SITE CHARACTERISATION OF THE WHATAROA VALLEY

FOR THE DEEP ALPINE FAULT DRILLING PROJECT STAGE 2 (DFDP-2),

WEST COAST, NEW ZEALAND.

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by

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Abstract

The Alpine Fault in western South Island ruptures every 300±100 years in large magnitude (7.8 ± 3) earthquakes and presents a major seismic hazard to New Zealand. The Deep Alpine Fault Drilling Project (DFDP) aims to drill, sample, and monitor the Alpine Fault in order to investigate the processes of earthquake genesis, rock deformation, and fault gouge formation for a tectonically active fault late in the seismic cycle. Rapid dextral reverse movements and exhumation rates on the central section of the Alpine Fault at Whataroa Valley make this a geologically favourable setting to drill and sample fault rocks at depth that can be correlated with surface exposures. The suitability of a site for stationing a major drilling operation depends upon practical issues such as the engineering geological characteristics of the proposed site, possible geohazards, and drilling logistics. This thesis presents new engineering geological, geophysical, and geomorphic investigations of the Whataroa Valley for the DFDP-2 drill site in order to provide a framework for proposed future operations.

MASW, GPR and basic geotechnical methods such as test pits and face logs were conducted at various locations at the site to gain geotechnical properties and attempt to find depth to bedrock. Results showed bedrock is at least 25m deep as it was not seen in any of the GPR surveys. Correlation of the MASW and GPR profiles with freshly eroded and face logged outcrops permitted assignment of s-wave velocities to each of the gravels present and confirmation of features seen in the geophysical surveys. V_s30 values gained from the MASW classed the gravels as a soft soil in Site Class D in NZS 1170.5. Expected peak ground accelerations at the study site during an Alpine Fault earthquake are estimated at ≥0.8g.

The Whataroa River is actively eroding the southern edge of the investigation area. Comparison of historic aerial photos and newly obtained LiDAR showed the river bank has moved a total of 165 m since 1948, a majority of that occurring in the past decade, 35 m of erosion occurring over a few days during early January 2011. Little correlation between heavy rainfall periods and increased erosion rates suggest changing channel dynamics play a major part in the channel migration. Modelling of the threshold discharges required to overtop the Whataroa terraces results in return periods several orders of magnitude larger than Alpine Fault earthquake recurrence intervals that result in major sediment pulses,

implying that inundation from river flooding under current channel conditions is highly unlikely.

Debris flows originating from the west valley wall have been identified as a possible hazard to drilling operations. Recent debris flows were easily mapped due to the changes in vegetation, whereas the remnants of historic debris flows were able to be mapped using the LiDAR. Studies of these show that they have a minimal run out distance (<100 m), and can be easily avoided by ensuring the drill site is located outside the proposed debris flow risk zone plus a 50 m buffer that has been added for caution.

Current uncertainty of the fault dip and target depth of the hole causes large variation in proposed drill rig locations at the surface. All of the investigations are summarised on a hazard map used to suggest a range of favoured drill sites based on varied angle dips and drilling depths, minimizing flood, erosion and sediment inundation hazards, and specifying access routes.

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1 Introduction

1.1 Project Background

Scientific drilling is an essential and fundamental tool of modern earth science research. It provides the only means of directly determining insitu properties of solid materials and fluids to gain information on processes operating in the subsurface. Drilling enables the testing of hypotheses and models developed from surface observations by using drill holes as natural laboratories and observatories for experiments and long-term monitoring of on-going active processes. However major drilling projects are expensive, therefore utilization of all available resources and existing knowledge, involvement of leading experts, and selection of an optimal drilling location are essential elements of an international scientific drilling program (Harms, Koeberl, & Zoback, 2007).

The Alpine Fault in the western South Island of New Zealand accommodates the movement between the Australian and Pacific plates with magnitude 7.8 ± 3 earthquake events that recur every 300±100 years (Townend, et al., 2008) and is a major seismic hazard for the entire country. The rapid exhumation of hanging wall rocks on the Alpine Fault has exposed a section of the mid-crust and has caused a higher geothermal gradient so the base of the seismogenic zone has been curved up and is presumably near drillable depths. The brittle-ductile transition zone is an important target for tectonic studies because most moderate to large crustal earthquakes nucleate there (Sibson, 1983). It is also the location of many geological-rheological transitions such as the transition from predominantly cataclastic to predominantly mylonitic rocks. Currently, our understanding mid-crust deformation is based on surface outcrops of faults and remote geophysical observations (Townend, et al., 2008).

The Deep Alpine Fault Drilling Project (DFDP) aims to drill, sample, and monitor the Alpine Fault in order to investigate the processes of earthquake genesis, rock deformation, mineralization, and fault gouge formation for a tectonically active fault late in the seismic cycle. The dextral reverse movement of the fault provides an opportunity to investigate its evolution by examining matching lithologies at two separate points on the same exhumation trajectory. To do this, two near-surface boreholes (DFDP-1a and DFDP-1b) were drilled adjacent to a well known and studied outcrop at Gaunt Creek, while another deeper hole (DFDP-2) will target a location on the fault that is down-trajectory from the lithologies sampled in the first hole. Essentially, the rock samples from depth are treated as the protolith of the modified rocks seen in the shallow borehole and at the surface. Differences in structural, mineralogical and geochemical properties will give an account of the geological deformation that has occurred (Townend, et al., 2008).

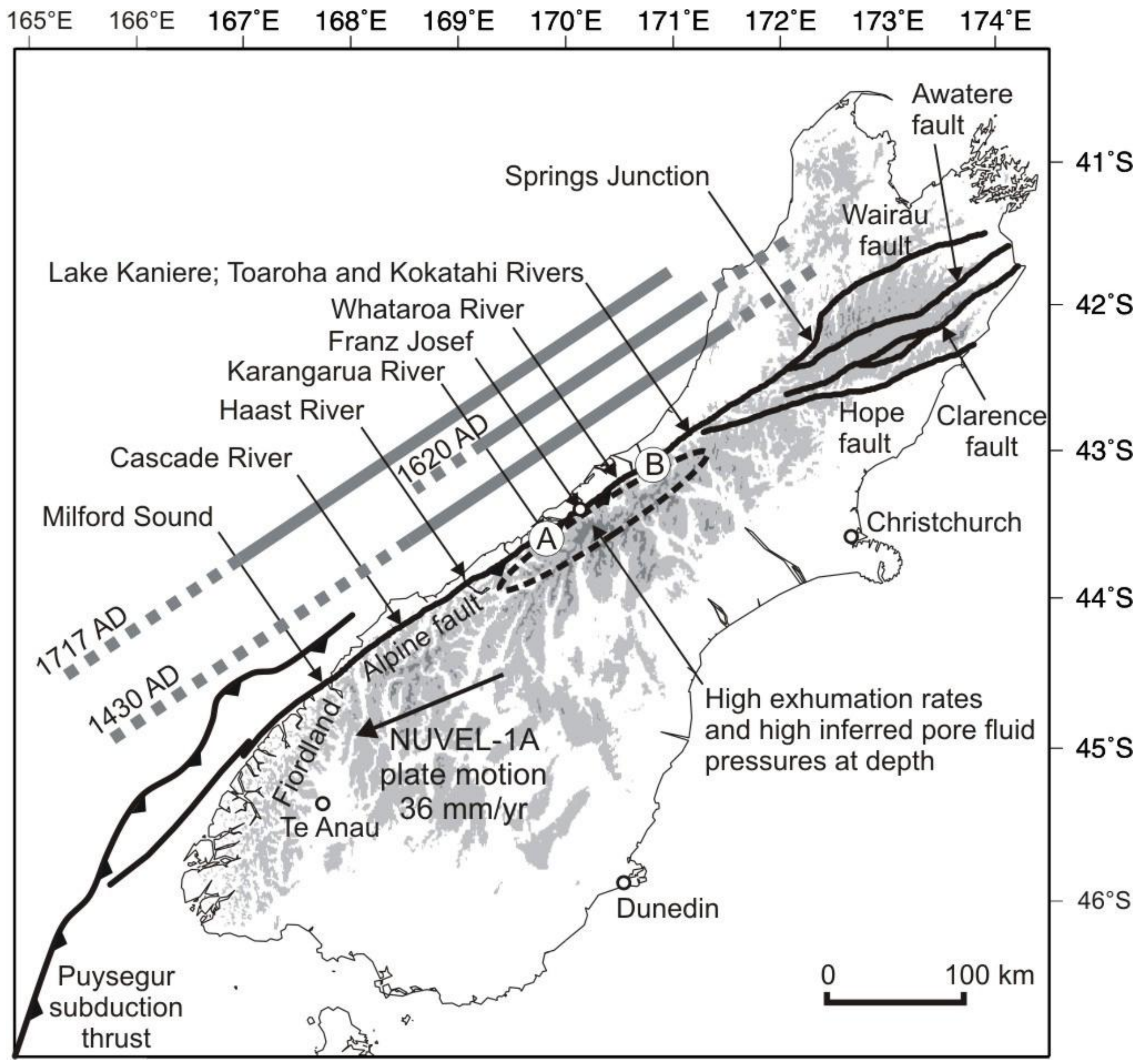


Figure 1.1 South Island map showing the Australia–Pacific plate boundary. The thick grey lines indicate the inferred extent of past Alpine Fault ruptures. "A" and "B" mark the extent of Figure 1.2 (Townend, Sutherland, & Toy, 2009).

Upon completion in February of 2011, borehole DFDP-1b was instrumented and monitored to record seismic activity, temperatures, changes in pore pressures and chemical composition. Stage two of the DFDP (DFDP-2) is a ~1.5km deep drill hole, proposed to be located in the Whataroa Valley on the West Coast, New Zealand. High exhumation rates on the central section of the Alpine Fault in this area and relatively easy access to the potential drill site make this setting geologically and logistically favourable to drill and sample fault rocks for stage two of the project.

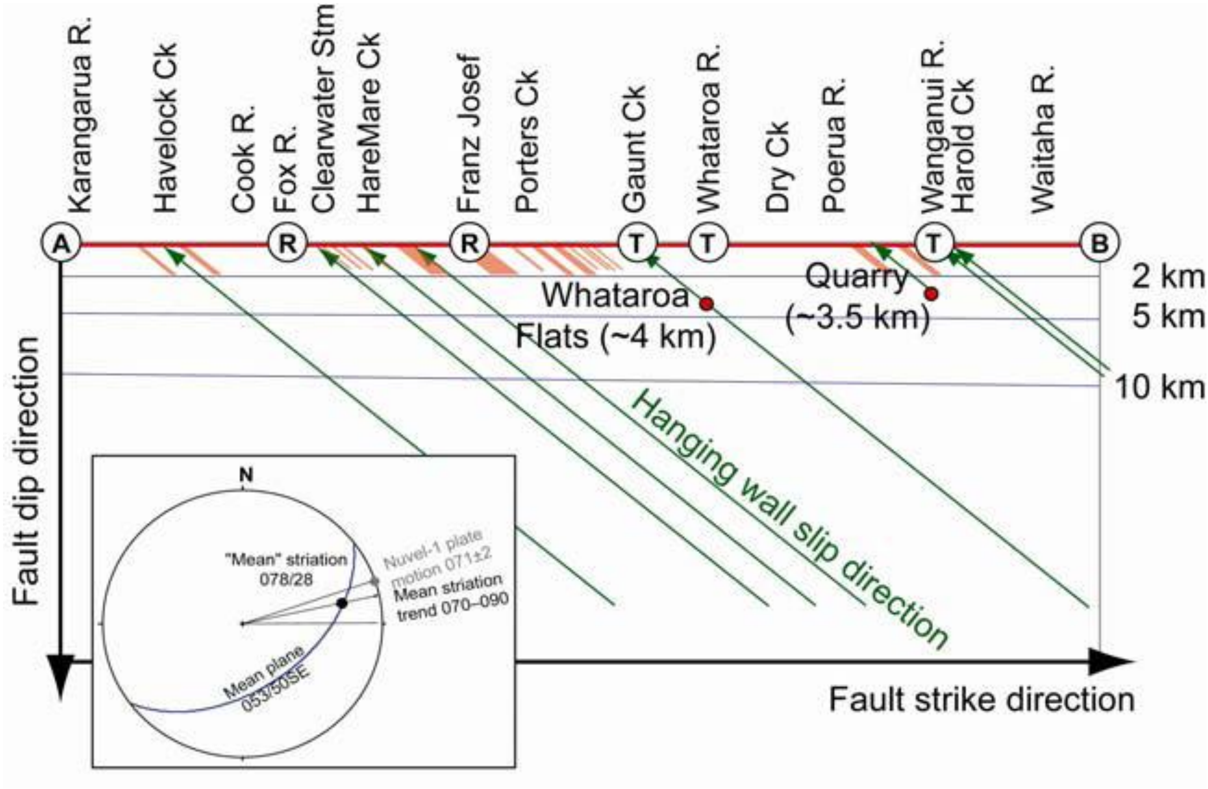


Figure 1.2 View normal to the mean fault plane in the central Alpine Fault region showing rock uplift trajectories and key outcrop locations. "T" and "R" indicate tracks and roads crossing the fault trace, respectively. The short red lines mark strike-slip portions of the fault trace. The inset summarizes the mean fault geometry in stereographic projection "A" and "B" are marked on Figure 1.1 above (Townend, Sutherland, & Toy, 2009).

The West Coast is a challenging and dynamic environment, due to its high risks posed by earthquakes, landslides, floods, and alluviation hazards. Straddling a plate boundary, models suggest earthquake and ground motion will be the highest (up to 3g) PGA in the country for a 475 year return period (Figure 1.3). Landslide events range from single rock falls, to catastrophic failures of whole mountainsides such as the Wanganui-Wilberg rock avalanche near Harihari. Additionally, the Southern Alps can receive rainfall between 12 and 15 m/yr, making it one of the wettest places in the world, and flood hazards are extremely common. Based on the 474 flood events that occurred between 1846 and June 2002, 3 floods happen per year (DTEC Consulting LTD, 2002). When considering sites for drilling and long term monitoring it is fundamentally important to characterise the near surface properties of the landscape and the relative hazards of different origins at that site.

1.2 Project Aims and Objectives

The aim of this thesis is to provide a framework for the DFDP-2 operations by producing a comprehensive set of engineering geology maps and a detailed assessment of the area under investigation for drill site in the Whataroa Valley.

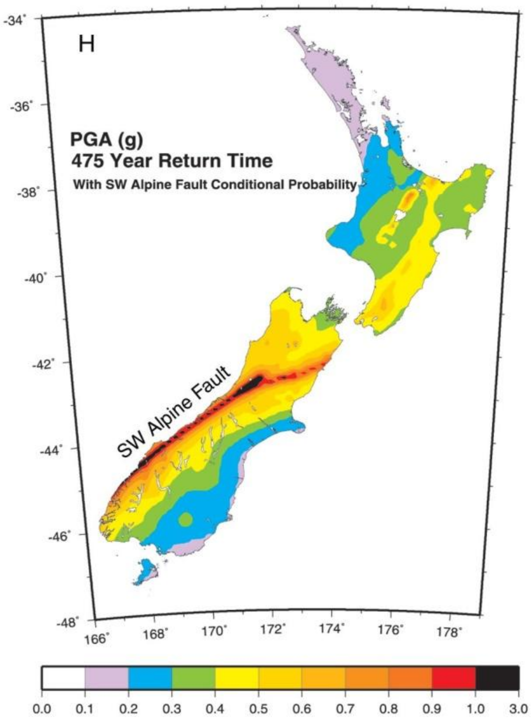


Figure 1.3 Probabilistic seismic hazard maps for New Zealand. Showing the levels of peak ground acceleration (PGA) with a return period of 475 years (i.e., 10% probability in 50 years) (Stirling, McVerry, & Berryman, 2002)

To identify specific objectives, a series of questions were asked about the investigation area:

1. What are the likely ages and origins of the Whataroa Terraces?
2. What are the subsurface characteristics and properties of materials present?
3. What hazards are present?
4. Where are there landslides and debris flows, both active and inactive and how can these be avoided?
5. How are active river dynamics likely to influence the stability of the terrace surface?
6. How does the sediment flux vary with earthquake magnitude?
7. How does accessibility affect drill rig placement?
8. Is there somewhere a drill rig could be placed to survive the hazards present?

This thesis first uses mapping, LiDAR, GPR, MASW, testpits, and traditional engineering geology descriptions to identify the different terraces and their composition, and characterise near surface (<30 m) material properties, such as s-wave velocity, stiffness, soil type, depth to bedrock, and water table positions. These properties are relevant for engineering considerations such as choosing a stable site and access road.

The second part of this thesis focuses on estimating relative hazard probabilities for a drill site at this location. Specific hazards that were addressed include site inundation from Whataroa flood waters and/or alluvium, burial from landslides sourced in the adjacent highlands, ground shaking, liquefaction and ground rupture related to an Alpine Fault event or more distant earthquakes, and site erosion from lateral migration and incision of the Whataroa River.

The third part of the thesis proposes a suite of possible scientific DFDP-2 drill site locations based on an integrated approach incorporating the scientific objectives of the project whilst locating the drill site in the most resilient location.

1.3 Deep Fault Drilling Project Background

1.3.1 Site Selection

To achieve the goals for drilling into the Alpine Fault, the project needs to be based within the central section where the uplift rates are highest. This section is bound by the Karangarua and Wanganui Rivers (Figure 1.4).

Five sites were considered using the criteria that the final results have to be scientifically relevant, significant, representative of the fault, and in the location of the highest uplift rates possible. Also the possibility to tie in with previous and future research needed to be considered, for example, the 1996 South Island Geophysical Transect Project (SIGHT), a deep crustal seismic project with lines running down the Karangarua and Whataroa Rivers, or the need for subsequent boreholes at different distances from the fault.

A list of logistical criteria needed to be taken into account as well (Townend, Sutherland, & Toy, 2009):

- Physical Access to the hanging wall.
- Permitting requirements.
- Site conditions/hazards affecting the site.
- Visibility/impact of the project on others.

Below the pros and cons of each of the five sites, based on a preliminary analysis are discussed (Summarised from Townend, Sutherland, & Toy, (2009).

1.3.2 Wanganui River

Access is easy, with an existing shingle road to a quarry approximately 3km from the fault line, and with the area having previously been quarried and away from public view, permits should not be difficult to obtain.

Scientifically there is an opportunity to correlate borehole data with surface fault observations in Harold Creek adjacent to the Wanganui River, however Harold Creek is a complex fault zone. Also, this site is away from the SIGHT profiles and is nearing the margins of the zone of highest uplift.

1.3.3 Whataroa River

With the addition and development of some roads and tracks there is easy access across farmland for approximately 3km. Some of this area could be prone to flooding. The primary use of this area is farming, with minor tourist activity, permits should not be difficult to obtain.

Scientifically, the Whataroa Valley was the location of one of the SIGHT transects, providing an opportunity to extrapolate borehole observations. Surface observations at Gaunt Creek (~7km away) can also be tied in with this site. Gaunt Creek is the most studied outcrop along the alpine fault. However, Whataroa could prove to be complex as it is the junction between a strike-slip and thrust segment of the Alpine Fault.

1.3.4 Waiho River

There is easy access along an existing road that extends about 4km away from the fault, although it is possibly prone to flooding. This site is in the middle of a highly protected national park with a high volume of tourist activity. Gaining permits, if possible, would be a very long and complex process.

Scientifically, the local outcrops are well studied and there is opportunity to correlate borehole data with a surface outcrop at nearby Docherty's Creek. Also it is between two SIGHT profiles that could also be correlated with borehole data.

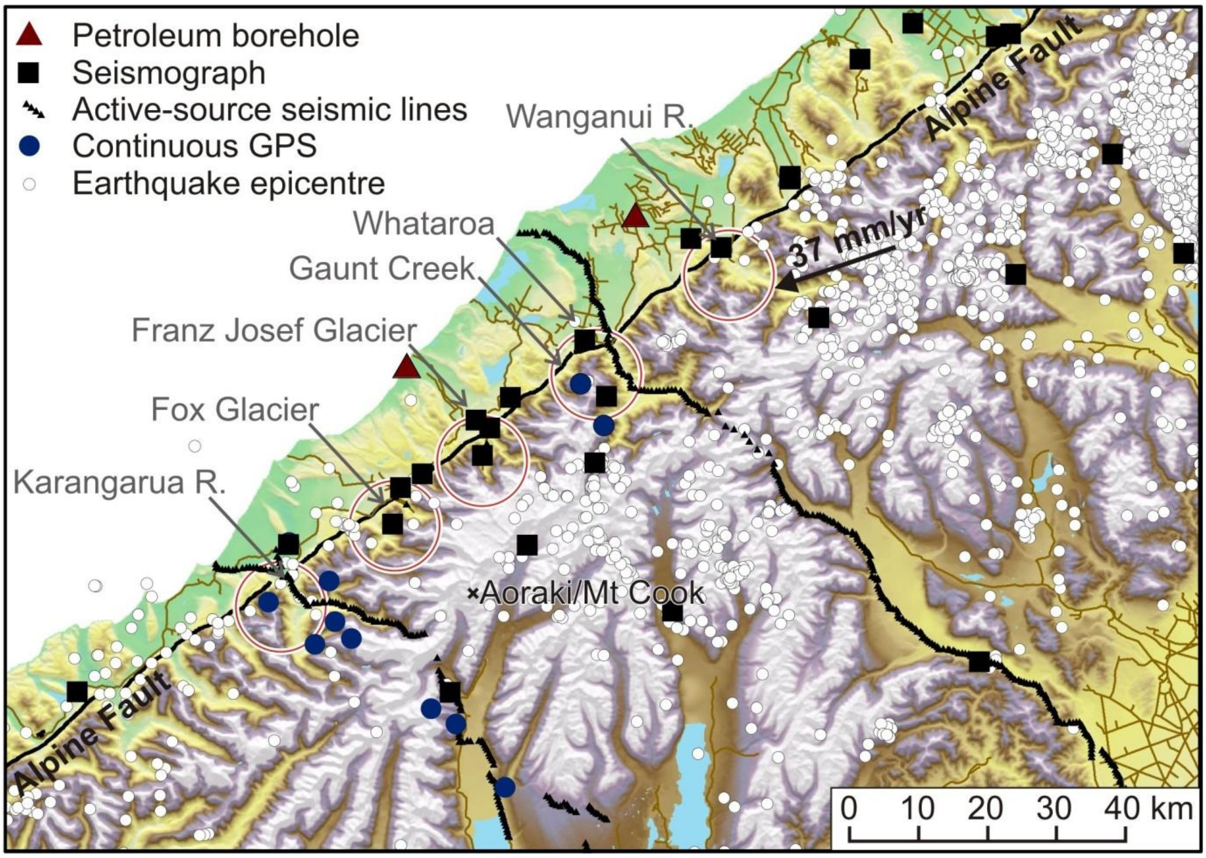


Figure 1.4 Map of the central Alpine Fault showing existing infrastructure, the onshore portions of the South Island Geophysical Transect (SIGHT) active-source seismic lines, background seismicity, and the locations of the possible drill sites referred to in Table 1 (large circles). (Townend, Sutherland, & Toy, Deep Fault Drilling Project - Alpine Fault, New Zealand, 2009)

1.3.5 Fox River

There is easy access along an existing road that extends about 4km away from the fault. Like the Waiho River this is prone to flooding and the site is also in the middle of a highly protected national park with a high volume of tourist activity, gaining permits, if possible, would be a very long and complex process.

Scientifically, this location is between two SIGHT profiles, however there are poor outcrops and the fault location is vague, this would create a lot of uncertainty when accurately placing the drill rig.

1.3.6 Karangarua River

This site is also in a high profile conservation area, and there is very little opportunity to build access roads.

Scientifically it has a surface outcrop in nearby Maimai Creek and it lies on a SIGHT transect.

1.3.7 Summary

Logistically the most favourable site would be the Wanganui River, as it has an already constructed road and is not under risk from hazards posed at other sites.

Scientifically favourable would be the Waiho River, or Whataroa, both with a lot of previous local research done and close to the area of greatest uplift.

The southern three sites, Waiho, Fox and Karangarua Rivers, all being within high profile conservation areas that act as hubs for major tourist activity, will prove either very difficult or impossible to gain permits to build access roads and drill pads etc. Therefore these should be effectively ruled out. Leaving either the Wanganui or Whataroa Rivers. Although the Wanganui River would logistically be more favourable, with minimal work, the Whataroa River would provide a much better scientific opportunity. Therefore, this site was considered the most favourable overall site.

1.3.8 DFDP-1 to date

To date, the first stage of the DFDP has been successfully drilled with two boreholes completed at Gaunt Creek, south of Whataroa. DFDP-1A was drilled to 100.6m and DFDP-1B to 151.4m. Wireline logging of the boreholes has been carried out with a wide range of tools such as natural gamma, calliper, electrical resistivity, spontaneous potential, density, porosity, full waveform sonic, dipmeter, and induction flow meter. Also, an observatory has been setup with a 2 Hz seismometer at the base of the hole, five piezometers to monitor pore fluid pressure, and 25 sensors to monitor the average temperature gradient in the borehole and detailed thermal structure immediately above the fault (Sutherland, 2011).

Figure 1.5 Drilling operations at Gaunt Creek for DFDP-1, with the well known and studied Alpine Fault outcrop in the background

1.4 Geological Setting

1.4.1 Alpine fault

Through the southern half of the South Island, the dextral-reverse, northeast-striking and southeast-dipping Alpine Fault accommodates 50%–80% of the 37 ± 2 mm/yr of convergent motion across the Australian and Pacific Plate boundary (Langridge et al., 2010). The ≥325-km-long central segment of the fault, has a strike-slip rate of ~27 ± 5 mm/yr and a varying dip-slip rate responsible for the uplift of the Southern Alps, ranging from 0 mm/year (Hokuri Creek to the south) to >12 mm/yr (Gaunt Creek in the central section) (Norris & Cooper, 2001). The Alpine Fault has a total dextral displacement of bedrock geology of ~480 km (Cox & Sutherland, 2007), this is illustrated by the offset basement rocks in Figure 1.6.

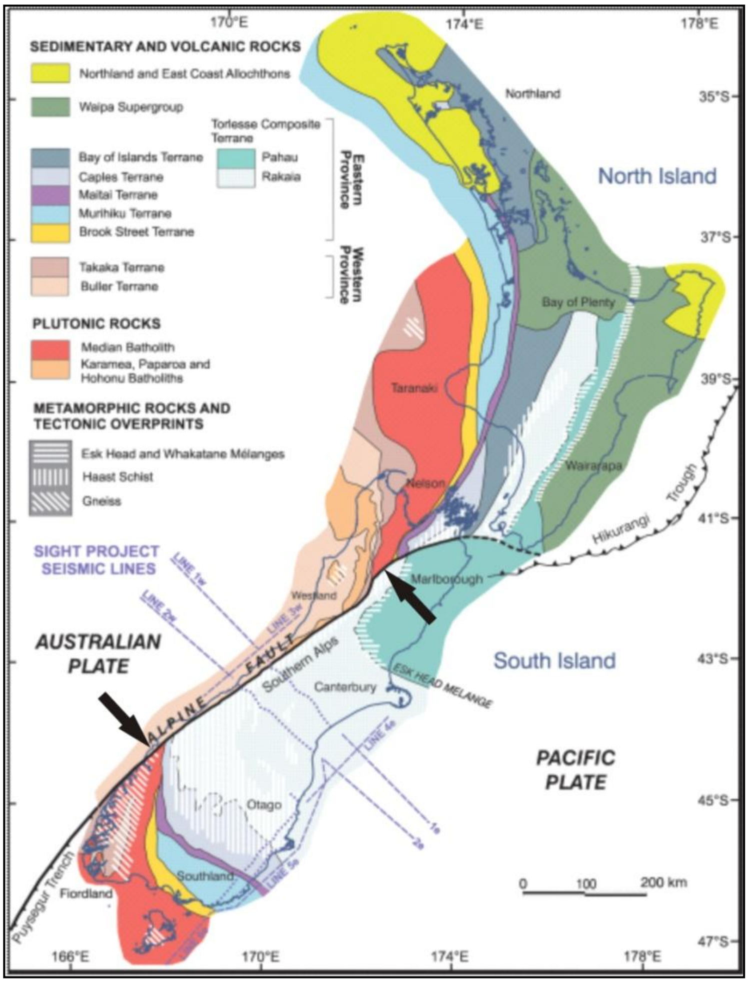


Figure 1.6 Basement geology of New Zealand. Illustrating the main terranes that were accreted against the margin of Gondwana during the Palaeozoic and Mesozoic. The black arrows mark the basement lithologies illustrating the Alpine Fault's ~480 km offset (Cox & Sutherland, 2007)

1.4.2 Basement rocks

The basement rocks in the South Island are divided by the Alpine Fault into two provinces, an Eastern & Western Province. In the central section where this study is located, west of the Alpine Fault is the Buller terrane, originally part of Gondwanaland. It is comprised of Early Palaeozoic sedimentary, metamorphic and plutonic rocks. To the east is the Torlesse composite terrane composed of thick, deformed packages of sandstone and mudstone from the Carboniferous to Early Cretaceous (Cox & Barrell, 2007). Some of this has been highly metamorphosed forming the Haast Schist and mylonites.

1.4.3 Quaternary

Extensive historic glaciations extending well offshore dominated the landscape during the Last Glacial Maximum (LGM). The last major advance occurred ~14 ka followed by rapid glacial retreat with minor advances (Suggate, 1990). Because of this widespread glacial activity, most of the landscape of the western Southern Alps is younger than 14ka. This, combined with the continued uplift and erosion of the Southern Alps provided an abundance of rock material has resulted in the formation of large gravel plains and terrace sequences.

2 Material Properties and Topography of the Lower Whataroa Valley

2.1 Introduction and Methods

This chapter identifies how the Whataroa landscape was formed and provides a framework of preliminary geophysical and engineering geology investigations for the DFDP-2.

The type and size of the drill rig used for this borehole will ultimately be decided by the hole diameter and final depth that is aimed for. If there is a need to build a semi-permanent or permanent structure for drilling or monitoring, basic geological characteristics of the area and engineering geology properties of the materials present will be useful. A wide range of geophysical, engineering geological and mapping techniques were used to collect data, these are outlined in Table 2.1.

The primary cultural use of this area is farmland, with some activity from the tourist industry including scenic helicopter flights, a historical gold panning business and recreational use as public access to popular tramping and hunting areas up the valley.

Table 2.1 summarises the methods used in this project and briefly states their purpose. Descriptions of each method, technical parameters and settings used for each setup, how the data was processed and the limitations of each dataset are discussed in Appendix A.

2.2 Geomorphology

2.2.1 General Terrace Morphology

The site can be split into two major terraces that have been attributed to aggradation events following the 1620 and 1717 AD Alpine Fault earthquakes (McSaveney, 2002), and a degradation terrace where the Whataroa River once incised the 1620 surface. There are remnants of older terraces at various points along the valley walls, these are outlined on the Whataroa Valley Geomorphology Map in Appendix B.

Table 2.1 Methods used. Descriptions of each method, technical parameters and settings used for each setup, how the data was processed and the limitations of each dataset are discussed in Appendix A.

Method	Purpose
Field Mapping	To produce a series of geomorphological and engineering geology maps which are presented in Appendix B.
Differential GPS (DGPS)	To create a topographic base map for the study and accurately map in geomorphic features such as terraces and particularly southern riverbank.
LiDAR	To obtain a detailed elevation model of the site for geomorphic mapping. An uninterpreted LiDAR map of the area is presented in Appendix H. This was used for the Whataroa Geomorphology Map in Appendix B and numerous figures throughout the thesis.
Scala Penetrometer	To use the scala penetrometer test to assess the strength of near surface materials.
Hand Auger	To use the Hand Auguring to gain subsurface soil profiles of the terraces.
Facelog	A face log of the 390m long gravel face along the eroding southern edge of the terrace was completed to map in detail the different lithologies present at the site and identify their characteristics and relative ages. The facelog was split into four ~100 m sections in Appendix C.
Testpitting	Explosives holes for the Whataroa Detailed University Seismic Imaging Experiment (WhataDUSIE) project were logged to gain information on the subsurface material. The testpit logs can be found in Appendix D. Their locations are illustrated on The Engineering Geology map in Appendix B.
MASW – Multi Channel Analysis of Surface Waves	To gain stiffness data on the materials as scala penetrometer tests failed, and identify if bedrock is present in the near surface (<30m). Depth to bedrock is important for identifying how deep casing should be installed in the borehole. Casing is a PVC or metal pipe put down the hole around the drill rods, to prevent borehole failure in the soil or loose rock sections of the borehole. The setup details for each survey are outlined in Appendix A, Table 5.1. The spread of the MASW surveys are illustrated on the Whataroa Geophysical Investigations Map in Appendix B. The uninterpreted profile and location of each MASW line can be found in Appendix E.
GPR - Ground Penetrating Radar	The goal of this investigation was to identify depth to bedrock. The setup details for each survey are outlined in Appendix A. The spread of GPR surveys is illustrated on the Whataroa Geophysical Investigations Map in Appendix B. The uninterpreted profiles and location of each GPR line can be found in Appendix F.

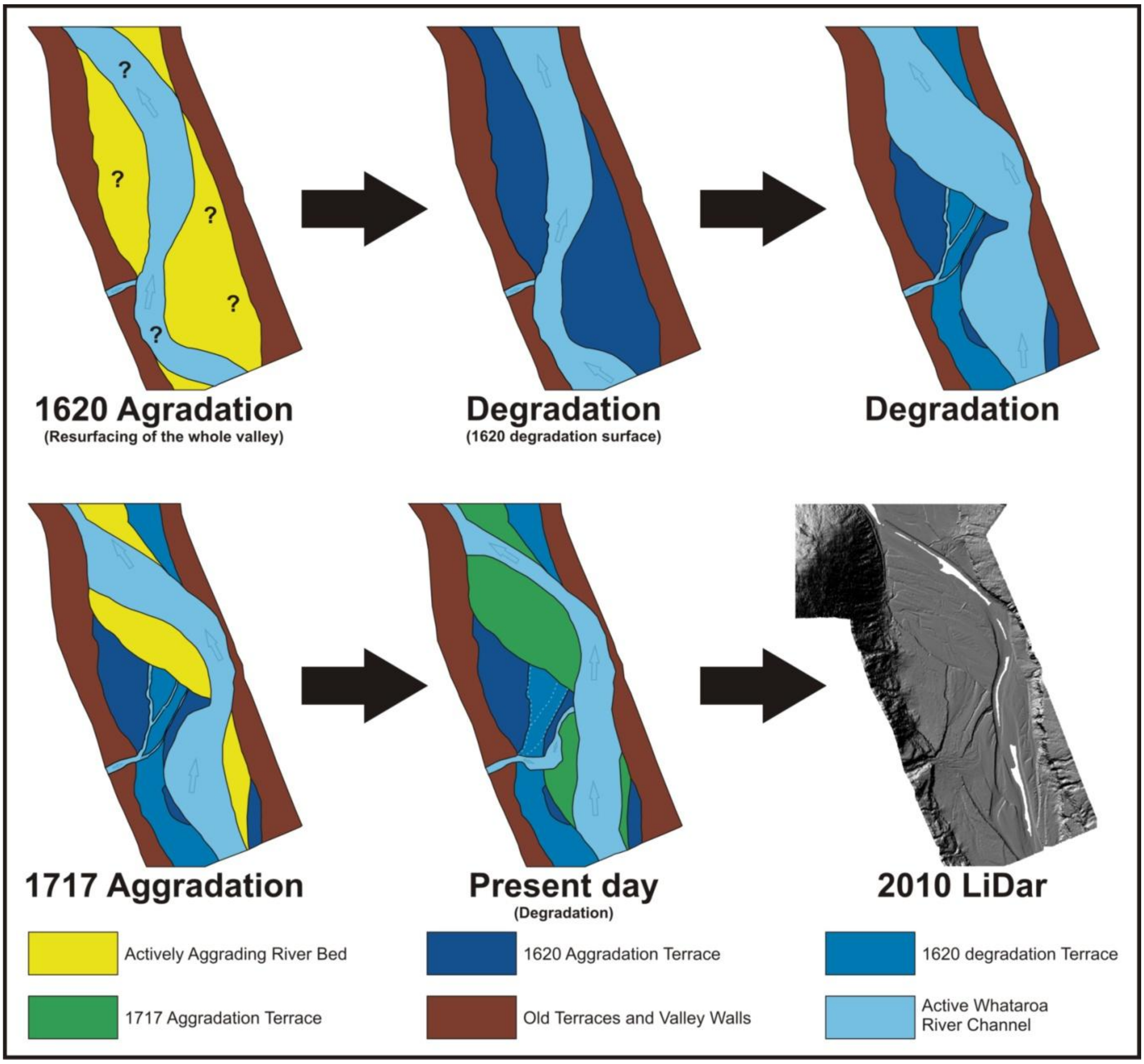


Figure 2.1 Possible terrace building sequence in the Whataroa Valley. Starting after the 1620 AD Alpine Fault event with a large aggradation event resurfacing the whole valley, followed by a number of different river channel positions. The final result is compared with the LiDAR image.

Trees located closer to the mountain range were established after 1717 indicating another aggradation event (McSaveney, 2002). These post 1717 forests are confined to the upper reaches of the alluvial fan suggesting a smaller aggradation episode during 1717. Less aggradation could be explained by either less available material due to a short time period between events or a smaller intensity earthquake. The 1620 event is thought to have been significantly smaller than the 1717 (Figure 1.1), so the short time period between the two events could be the cause for less aggradation. A longer period between shaking events allows a greater opportunity for weathering to occur, possibly providing more loose material. Due to this, with a nearly 300 year gap since the last event, we could expect very heavy aggradation in the next major earthquake.

The results of this study (McSaveney, 2002), although based on the alluvial fan, can allow us to assume the ages of the major surfaces at the drill site in the Whataroa Valley, however it should be noted that these are inferred from terraces downstream, and there is a possibility that they may be incorrect.

Figure 2.1 proposes a model for the formation of the terrace sequence in the Whataroa Valley based on field mapping and assumed terrace ages.

All terrace surfaces vary between solid river gravels, sands, and swamps. Towards the valley walls, there are a number of landslides and debris flows with accumulated material at the base, some of which have a constant stream running down them, these are discussed in more depth later in this chapter. Each surface is separately discussed and has been mapped on the Whataroa Geomorphology Map in Appendix B.

2.2.2 1620 Aggradation Terrace

Some of the 1620 terrace was cleared for farming in the 1980's (Friend, 2010, pers comms), however it is dominated by native bush, through which, runs a complex network of small streams originating from the valley walls that meet at the northern tip of the terrace and drop down to join the stream on the 1717 terrace. Most of the old river channels on the 1620 terrace have been eroded and smoothed out or buried, possibly by landslide debris from the valley wall. Certain areas on this terrace are hummocky and resemble the surface of a debris flow deposit. This is in the area that was cleared for farming. Reworking of this surface with heavy machinery could have shaped it that way. These features are discussed in Chapter Three.

There is an anomalous North West trending feature on this surface that could be interpreted as a fault or an old channel and terrace. The origin of this feature is discussed in Chapter Three.

2.2.3 1620 Degradation Terrace

The 1620 terrace has a degradation surface present on its eastern half where the Whataroa River likely flowed for a period of time. It is possible that the substantial stream running in from the valley wall flowed along here afterwards, creating some of the smaller channels (Figure 2.1). At some point, possibly during the 1717 earthquake, this has avulsed and now flows directly down to meet the present day river to the south of the study area.

2.2.4 1717 Cut and Fill Terrace

Aggradation from the 1717 episode is estimated to be between 5 – 8 metres within the main Whataroa Valley (McSaveney, 2002), spilling out and thinning over the Whataroa alluvial fan, subsequently covering the trace of the Alpine fault. This fits with observations in the facelog. The 1717 cut and fill terrace averaged ~6m thick with a minimum thickness of 4 m. The terrace was mostly cleared for farming, with two patches of native bush remaining. The surface looks a very young age, as old river channels and features are still very obvious and bouldery river sediments outcrop at the surface and there is minimal topsoil development.

The old river channels comprise a network of streams and ephemeral channels that trend towards the northeast. These channels join to create a stream that runs along the valley wall, and meets the Whataroa River at the northern tip of the terrace.

2.3 Materials

The face log (Figure 2.4 & Appendix C) identified a number of different materials. There is variation across all the units however here they have been described as six separate lithologies. Three gravels, each of which are thought to be from corresponding Alpine Fault rupture events at 1420, 1620 and 1717, as well as two silts, and a coarse sand. One 100 m section of the face log is shown in Figure 2.4 as it is represents features found on all logs. All sections of the facelog can be found in Appendix C.

From interpretation of the facelog, we suggest that the 1420 gravel is present at the bottom of the entire face. The 1620 gravel was subsequently deposited after a major earthquake, followed by a clayey silt overbank deposits. This sequence can be seen on the south half of the face. The Whataroa River then incised through the 1620 gravel unit, and slightly into the 1420 gravel. After the 1717 earthquake, aggradation occurred atop this 1420 contact, but was not extensive enough to over top the 1620 surface. Deposition of thin layers of sandy silt overbank deposits has occurred since. This section can be seen on the northern half of the face log.

Figure 2.2 Failure of the 1717 Gravel unit.

The 1717 and 1620 gravel units have slight imbrications of the gravels, suggesting paleo flow directions into the gravel face, and there is a definite trend of fining upwards with a majority of the large boulders lining the bottom of the unit. These characteristics could suggest it was deposited relatively rapidly after a shaking event, as directly after an event is when there will be an abundance of large material, this would be the source of the large bouldery base of the units. Both the units are very loose with occasional large sand lenses within them, and they regularly have boulders and over hanging debris falling off and collecting at the base of the river bank as colluvium. Following completion of the facelog, there was a small failure of the 1717 gravel cliff face (Figure 2.2). This is the first instance of this happening in the last two years, it is not a regular feature of this unit and is likely due to high pore pressures built up during a storm combined with the water table from the nearby pond (Figure 2.3).

The 1420 gravel unit has an apparent fluvial structure that suggests the paleo flow direction during deposition that is parallel with the current riverbank. The gravels are more competent and show signs of very slight weathering and iron staining in spots. The gravel size is a lot smaller than the 1620 & 1717 gravel and it also shows a trend of fining upwards. It is possible that this too could get coarser towards the base and be comparable to the

1620 and 1717 gravels boulder size, suggesting an earthquake triggered deposition event. However, the visible section of this unit suggests it was deposited during a period of relatively lower sediment input.

Figure 2.3 Pond possibly providing heightened pore pressures near the river bank edge where the 1717 AD gravel unit failed.

Materials in the testpits ranged from coarse sands to very bouldery sandy gravels, with a few locations with minor silt layers. A number of trends were identified through the testpitting process. Firstly the difference in topsoil thickness, the northern end of the fan was notably thinner than further to the south, suggesting younging of the fan to the north. The other trend was the thickness of sand layers atop the gravel, to the south there is very little or no sand at the surface, to the north the sand increases. Images A, C & D on Figure 2.5 illustrate both this thinning of topsoil and thickening of sand to the north. There was some variation in these trends, for example, testpits that were entirely composed of sand (Figure 2.5B), these have been interpreted as old sand bars. Also, spots where topsoil has accumulated rapidly compared with the adjacent areas, most likely due to swamps and ponding.

2.3.1 Engineering Geology Descriptions

Engineering descriptions were obtained from both the facelog and the testpits. The sediments present at the site are extremely variable, even on a metre scale. Here they are classified into five different units, and described using the NZGS Guideline for the Field Classification and Description of Soil and Rock for Engineering Purposes (NZGS, 2005), and given a Unified Soil Classification System (USCS) symbol.

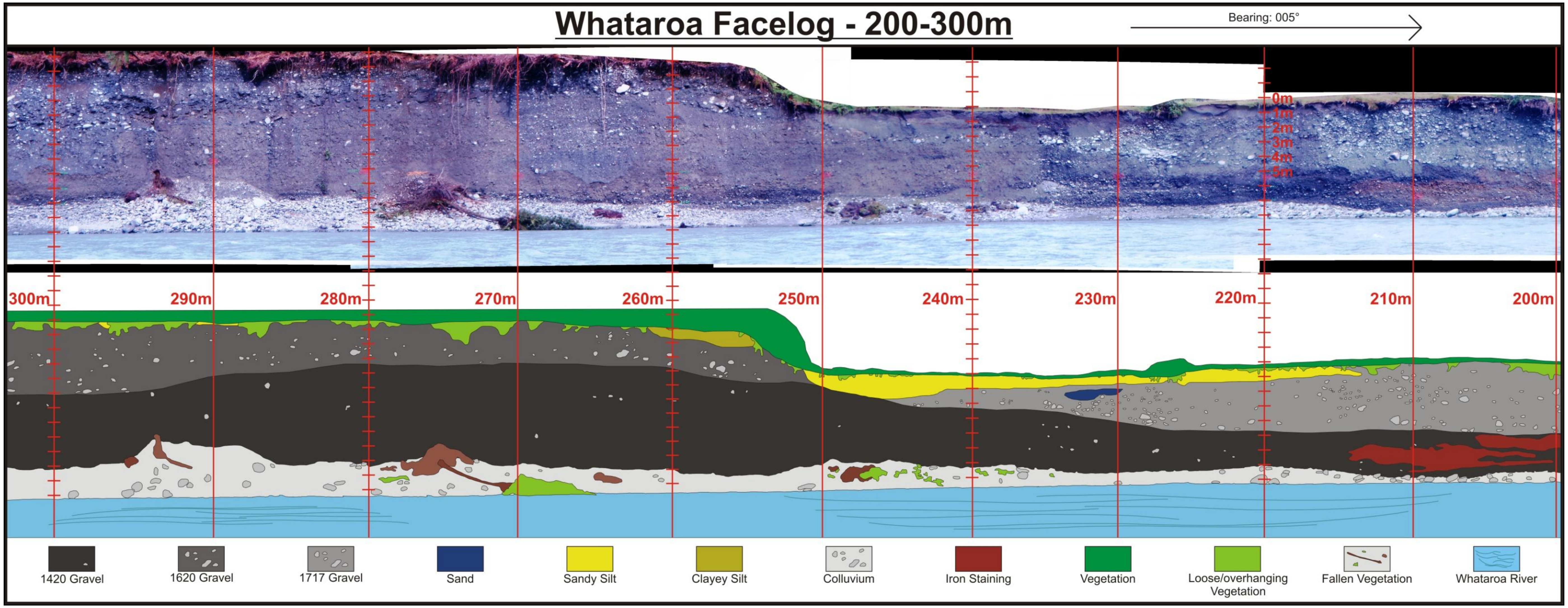


Figure 2.4 200-300 m of the facelog. This 100m section of the facelog is representative of all the features seen along the riverbank. All sections of the face log can be found in Appendix C. The facelog was done soon after an event causing a large amount of erosion, therefore, there is good exposure of the units present, particularly the lower 1420 AD gravel. The 1420 AD gravel has areas of iron staining, possibly indicating its much older age. The 1620 AD and 1717 AD units have identical descriptions, both with large boulders and sand lenses. The silts atop each surface are interpreted as overbank deposits from flood events before the river had incised. Descriptions of each of the units present here are outlined in section 2.3.1.

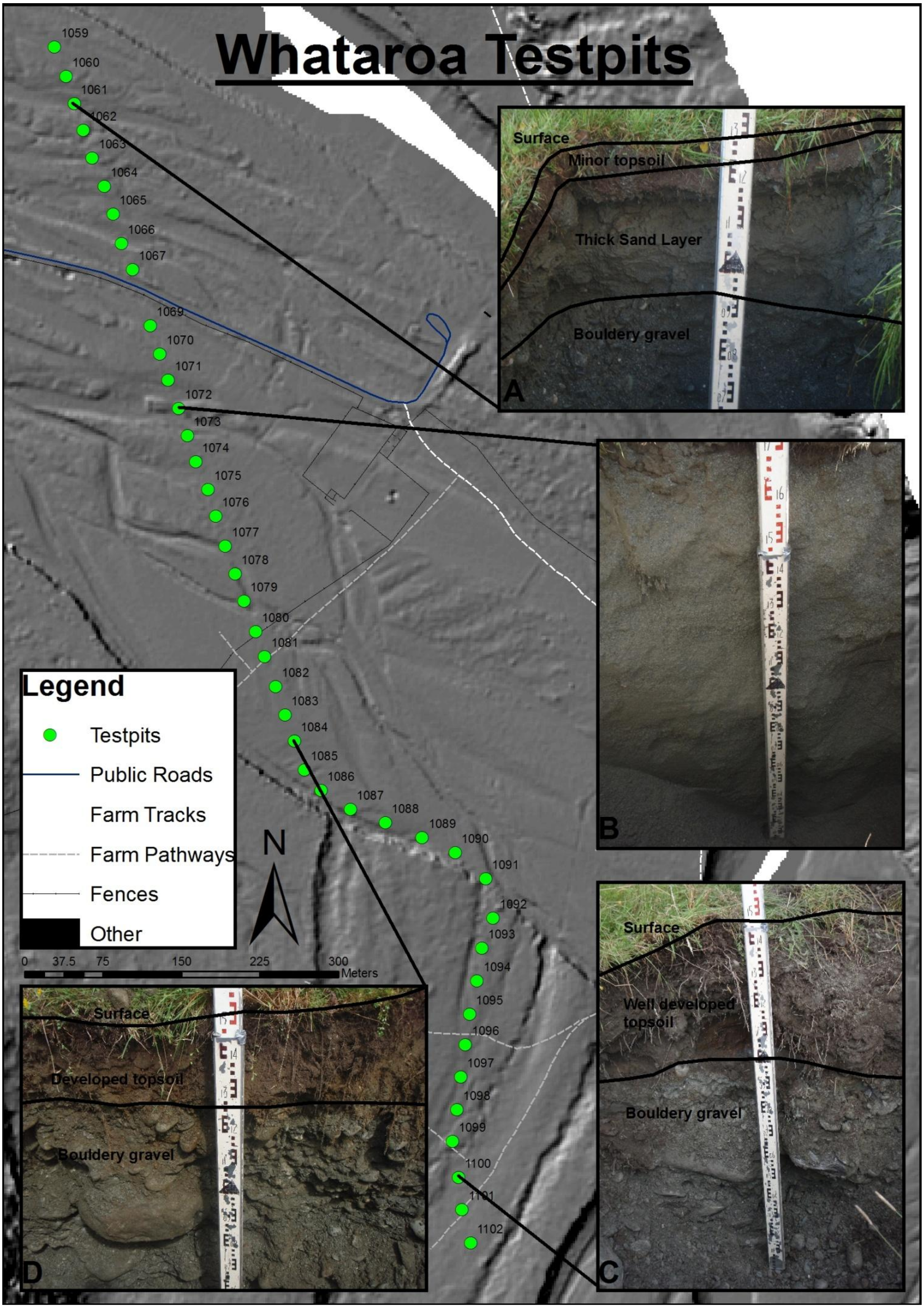


Figure 2.5 Whataroa testpit locations and selected testpit images illustrating the presence of sand bars (B) and the change in sand and topsoil thickness across the fan(A,C & D).

1420 Gravel

a) **Proportions of particle sizes:**

Gravel:	60%
Sand:	15%
Cobbles:	20%
Boulders:	<5%
Clay:	<5%

Figure 2.6 Lower Gravel Unit showing lenses of different sized gravels and sands.

b) **Maximum particle size:** 26cm

c) **Grading:** Well Graded

d) **Particle shape:** Angular to sub-rounded

e) **Particle strength/hardness:** Hard unweathered rock, some schist slightly weathered

f) **Colour:** Dark Grey

g) **Geological information:** Predominantly Gneiss and Schist clasts, some Greywacke. Clay likely derived from weathered schist.

h) **USCS Symbol:** GW

i) **Insitu description:** Sandy, fine to coarse GRAVEL with cobbles and minor boulders and clay, dark grey, bedded. Loose, moist, well graded, fluvial structures, non plastic, Angular to sub rounded Gneiss and slightly weathered Schist gravel with rare Greywacke clasts, fine to coarse sand, Minor fraction.

j) **Comments:** Fining upwards, occasional small very coarse sand lenses. There are a number of fluvial structures creating layers of different sizes of gravel and sands, this can be seen in Figure 2.6.

1620 & 1717 Gravel

a) Proportions of particle sizes

Gravel: 40%

Sand: 25%

Cobbles: 20%

Boulders: 15%

Figure 2.7 1620 & 1717 Gravel Unit illustrating the large boulders present and the upwards fining of the unit.

b) Maximum particle size: 1m

c) Grading: Well graded

d) Particle shape: Sub-angular to sub-rounded

e) Particle strength/hardness: Hard unweathered rock

f) Colour: Grey

g) Geological information: Slightly metamorphosed Greywacke Boulders, cobbles and gravel, rare schist & gneiss boulders.

h) USCS Symbol: GW

i) Insitu description: Sandy fine to coarse GRAVEL with cobbles and boulders, grey, bedded. loose, moist, well graded, thick horizontal bedding, non plastic, sub angular to sub rounded unweathered slightly metamorphosed greywacke gravel, fine to coarse sand, sub angular to sub rounded unweathered slightly metamorphosed greywacke cobbles and boulders.

j) Comments: Fining upwards. Large sand lenses present.

Coarse Sand

a) **Proportions of particle sizes:**

Sand: 95%

Fine Gravel: 5%

Figure 2.8 Coarse Sand – very uniform coarse sand.

b) **Maximum particle size:** 3mm

c) **Grading;** Poorly Graded

d) **Particle shape**

Sub-rounded to angular

e) **Particle strength/hardness:** Hard unweathered rock

f) **Colour:** Grey

g) **Geological information:** Likely derived from Greywacke

h) **USCS Symbol:** SP

i) **Insitu description:** Subordinate fraction, Major Fraction, Minor fraction, Colour, Structure, Strength, Moisture condition, Grading, Bedding, Plasticity, Sensitivity, Major fraction composition and rounding, Weathering of clasts, Subordinate fraction, Minor fraction, Additional structures

j) **Comments:** Appears in lenses within the 1620 and 1717 gravels, and in sand bars towards the north of the fan.

Clayey Silt

a) Proportions of particle sizes

Silt: 90-95%

Clay 5-10%

b) Colour: Dark brownish grey

c) Geological information: Post 1620 overbank deposits.

Figure 2.9 Clayey silt – present atop the 1620 surface.

d) USCS Symbol: ML

e) Insitu description: SILT, trace of clay, dark brownish grey, soft, moist, very slightly plastic.

Sandy Silt

a) Proportions of particle sizes

Silt: 90-95%

Fine Sand:5-10%

b) Colour: Dark Grey

c) Geological information: Posy 1717 overbank deposits.

Figure 2.10 Sandy Silt - present atop the 1717 AD surface.

d) USCS Symbol: ML

e) Insitu description: SILT, trace of fine sand, dark grey, soft, moist, non plastic.

f) Comments: Lenses of slight grain size difference

2.3.2 Engineering properties and behaviour

Although no successful direct measurements on the bearing load capacity of the materials were completed in this study, information on their strengths and behaviour can be estimated from published information on generic lithologies.

Classification		Grain Size	Sorting	Dry density (pcf)	Friction angle (deg)	Cohesion (psf)	Permeability (fmp)	Storage capacity	Seismic velocity (fps x 1000)	Resistivity (ohm-m x 1000)
Geologic	USCS									
Alluvial										
High energy	**GW, GP, GM**	Med-coarse	Med-good	115-130	30-35	0	0.01-10	0.1-0.3	1.5-5 dry 5-7.5 wet	0.3-30 dry 0.2-20 wet
Low energy	**ML, SM, SP, SW**	Fine-Med	Med-good	90-115	15-30	0-500	0.0001-0.1	0.05-0.2	1-4 dry 3.5-6 wet	0.01-10 dry 0.001-1 wet

Table 2.2 Descriptive properties of soil, taken from (Koloski, Schwarz, & Tubbs).

Classification		Relative erodability	Excavation difficulty	Moisture sensitivity	Foundation support (psf)	Cut slopes (%)	Seismic hazards	Common uses
Geologic	USCS							
Alluvial								
High energy	**GW, GP, GM**	Low	Low	Low	1500-2000	50-65	Low-Med	Aggregate, Fill
Low energy	**ML, SM, SP, SW**	Med-High	Low	Med-High	500-1500	25-50	Med-High	Fill

Table 2.3 Interpretive properties of soil, taken from (Koloski, Schwarz, & Tubbs).

The above tables provide a loose guideline to the properties and behaviour of the materials at the site. It should be noted that these are generalised values and are not measured data from the site, if any construction project needed these values they should be measured directly from the materials present.

In the descriptions earlier in this chapter, the two gravels were classed as GW on the USCS classification, so properties and behaviour can be taken from the high energy alluvial section of the tables. The sands and silts were classed as SP and ML, so properties and behaviour can be taken from the low energy alluvial section of the tables.

The definition of “Good Ground” in NZS 3604 for Timber-Framed Buildings is:

“Any soil or rock capable of permanently withstanding an ultimate bearing capacity of 300 kPa (i.e. an allowable bearing pressure of 100 kPa using a factor of safety of 3.0)”

The indicated foundation support for alluvial gravels in Table 2.3 converts to ~70 – 95 kPa. Having properties very close to the requirements for a timber frame building would suggest the gravels present at the site are competent enough to support a temporary drilling structure and monitoring station. If a more substantial structure was to be planned for the project, minor work such as vibration compaction would bring the foundations up to standard with NZS 3604.

Additionally, we attempt to use MASW profiling to provide geotechnical parameters for near surface materials.

2.4 Whataroa Terrace MASW

MASW was used as an attempt to identify depth to bedrock and simultaneously gain geotechnical properties of the materials at the site. A description of the method, collection and processing parameters used in these surveys are specified in Appendix A. The three survey locations on the Whataroa terrace can be seen in Figure 2.11. and the Whataroa Valley Geophysical Investigations Map in Appendix B. The raw results of each of the lines and their start and finish locations can be seen in Appendix E.

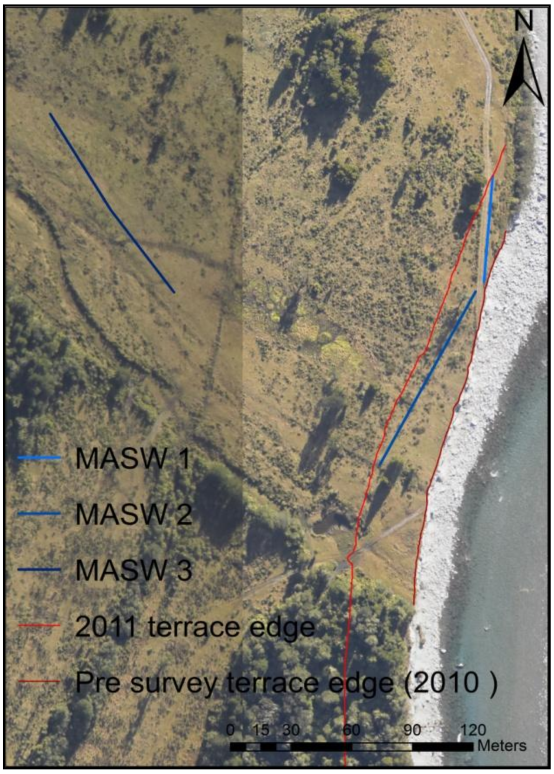


Figure 2.11 MASW Survey Locations in relation to River Migration.

All of the lines seem to have a definite jump in s-wave velocity at 4-6m depth, suggesting some kind of boundary. Line three received greater penetration and saw another possible boundary at ~15 m depth. There is a lot of scatter in the records, this was expected due to the close proximity to the cliff and receiving reflected surface waves was likely, however this can also suggest the presence of large boulders in the substrate.

Lines One and Two were compared with the river bank exposure to correlate the results with lithologies (Figure 2.13). The erosion of the river bank provided a great opportunity to do this, as the 2011 bank position nearly intersects exactly with the north of Line One, and the south of Lines Two, meaning that those specific spots in the survey are the actual lithologies currently seen in the riverbank outcrop.

Both lines correlate very well with the outcrop. At the north end of line two there is a zone of high shear wave velocities which corresponds well with the boundary between the two gravel units, the high velocity area disappears from the profile at the same point the lower gravel drops down. This suggests that the 1717 Gravel has a shear wave velocity range from ~200 - 350m/s, dropping slightly below that in very sandy areas. The 1420 Gravel has a shear wave velocity of ~450 - 600m/s. The other obvious correlation that can be made from Line two is the large white spot near the centre, this matches up very closely with a large sand lens in the river bank, suggesting a shear wave velocity of 100m/s, increasing up to 250m/s as the gravel content increases.

In Line One the same boundary at the depth of the 1420 Gravel contact was present, and the 1717 gravel unit seems to have an overall higher average s-wave velocity, this could be due to a higher concentration of large boulders. Line Three showed a distinct boundary at 15 m depth, and a slightly fainter boundary around 5 m depth. This is possibly an area where the 1420 gravel has a higher sand content and is returning slightly lower s-wave velocities, and there is a new gravel unit present at 15 m depth. A new gravel contact at this depth fits with interpretations of some of the GPR lines discussed in Section 2.5. Figure 2.12 and Figure 2.13 show interpretations for all the MASW surveys.

As there is a lot of variation in the gravels, particularly the 1717 gravel unit, s-wave velocities will drastically vary on the small scale, large single greywacke boulders will show velocities of 500 m/s and above (Duffy, 2008), and as seen in the sand lens, the sands give an s-wave velocity of 100 m/s . However a MASW profile produces an average s-wave velocity for the unit, therefore giving it a range of velocities from 200 – 350 m/s, this will depend on the ratio of gravel and boulders to sand at any given point. The 1420 Gravel unit shows a sharp increase in s-wave velocity. Minor clay content in this unit suggests it is a lot older than the overlying unit, therefore it is likely much denser. Less sand in its composition could also be contributing to its higher velocities.

Summarising the results, a range of s-wave velocities for each of the units was obtained (Table 2.4). The silts present at the site were too minor to pick up as a separate unit in the surveys.

Table 2.4 S-wave velocities of materials in the Whataroa Valley

Unit	Shear wave velocity range (m/s)
1717AD Gravel and 1620 Gravel	200 - 350
1420AD Gravel	450 - 600
Coarse sand	100

2.4.1 Geotechnical Property Correlations

There are a number of papers available that report s-wave velocities for a variety of different lithologies paired with the units measured engineering properties such as density, solidity and N-value (Inazaki, 2006) (Fumal, 1987). (N-value is penetration resistance value commonly used for assessing soil strength). An attempt was made to interrogate these papers for a range of inferred engineering values for the gravels and sands present at the site.

The study by Fumal (1978), investigates how different properties and characteristics have an effect on s-wave velocities, the major factors are briefly discussed here. Texture is said to have the largest effect, with a general trend of s-wave velocity increasing with average grain size Figure 2.14. The next major factor to influence s-wave velocity is depth. Fumal documents large overlaps in s-wave velocity at very shallow depths (0 < 5 m), and an overall general trend of increasing s-wave velocity with depth (Figure 2.16). Possible explanations for increased velocity with depth are changes in effective stress and void ratio due to increasing overburden load (Figure 2.15), as s-wave velocity is said to correlate well with density and void ratio (Fumal, 1987). When discussing this aspect, water content also becomes a factor, as lower values of saturation lead to larger void ratios decreasing shear wave velocity.

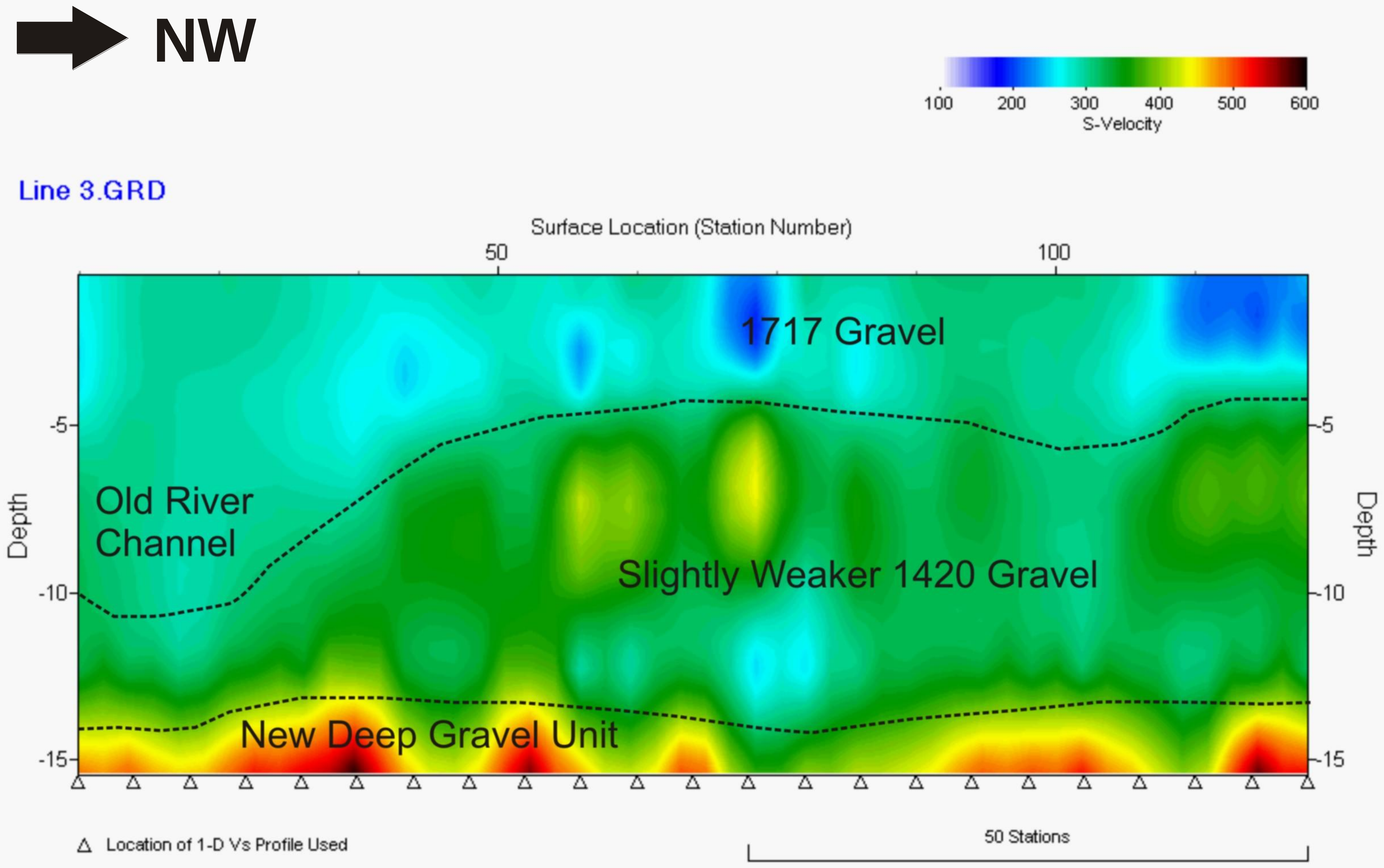


Figure 2.12 Interpretation of MASW line 3 – What could possibly be a weaker 1420 gravel unit and a new gravel unit appearing at 15 m depth. The location of this survey is shown on Figure 2.11.

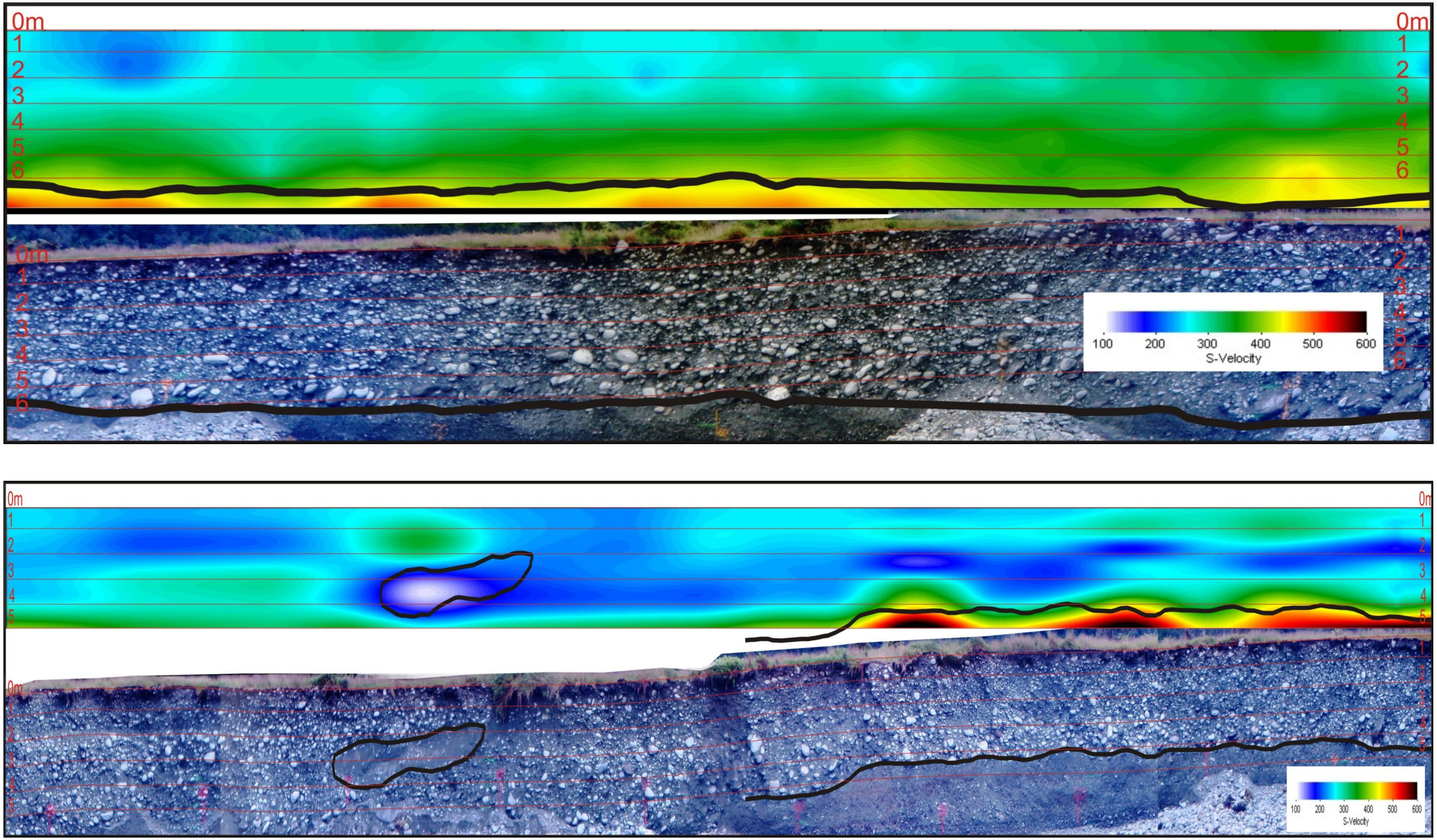


Figure 2.13 (top) MASW line one compared with the riverbank outcrop. (bottom) MASW line two compared with the riverbank outcrop. Both of these surveys show a strong correlation with the riverbank outcrop. The contact between the two gravels is highlighted by a large jump in s-wave velocity on both surveys. Line two shows a very low s-wave velocity zone matching up with a very loose sand lens. The location of these surveys is shown on Figure 2.11

NE

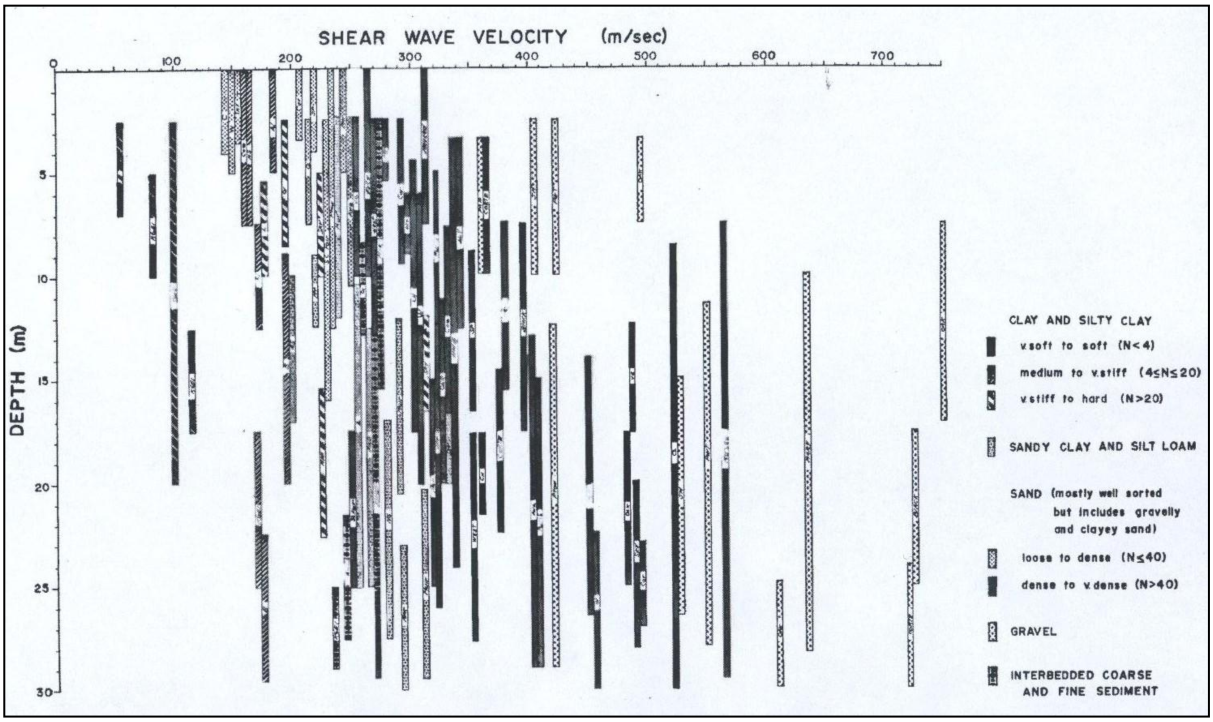
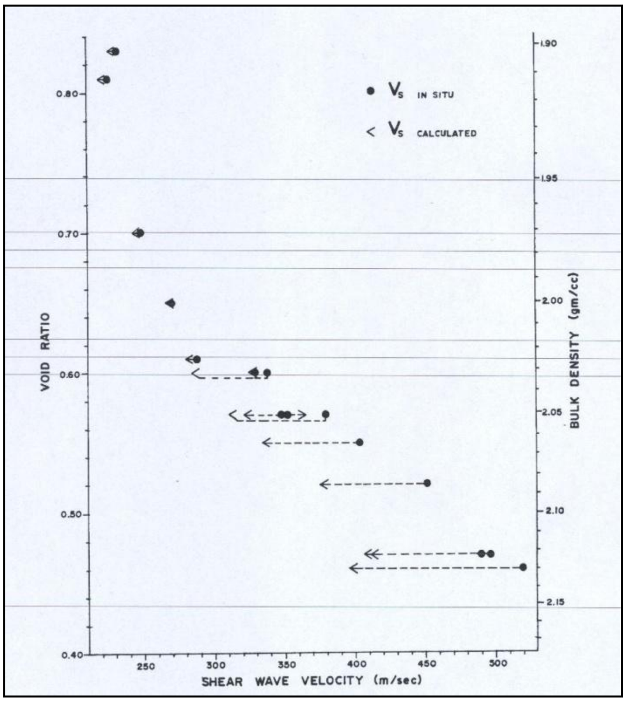


Figure 2.14 s-wave velocity-depth intervals for unconsolidated to semi consolidated sedimentary deposits differentiated according to physical properties (Fumal, 1987)



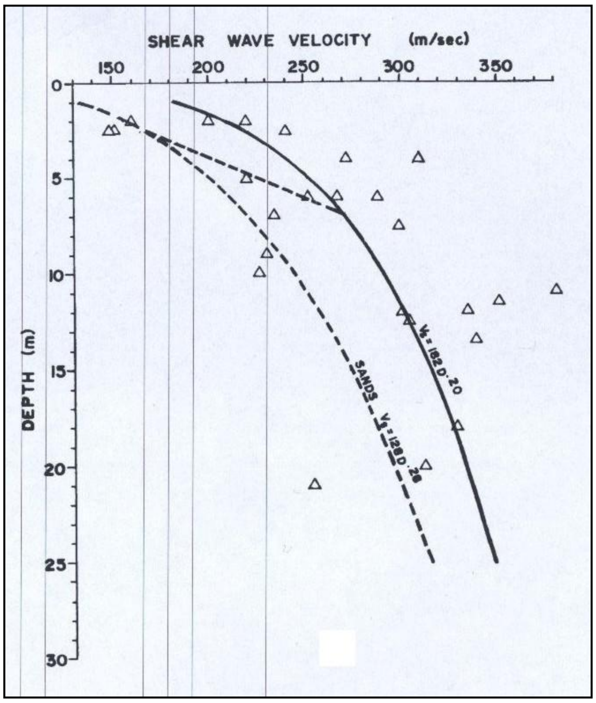


Figure 2.15 Variation with void ratio of s-wave velocity. (Fumal, 1987)

Figure 2.16 Comparison of s-wave velocity with depth for a range of sands. (Fumal, 1987)

Finally, Fumal (1987) attempts to correlate s-wave velocity with the Standard Penetration Test (SPT) test (Figure 2.17), and states that due to large scatter in the plot a useful correlation cannot be drawn. Inazaki (2006) suggests that you can estimate N-value with the graphs and equation in Figure 2.18 with measured s-wave velocity by PS suspension logging, as this gives a much higher resolution of the sub surface profile. This is because an N-value is recorded cumulatively with a (SPT) over 0.5 m intervals therefore is sensitive to small variations in subsurface strength, whereas s-wave velocity unless recorded in high resolution is usually averaged over many metres.

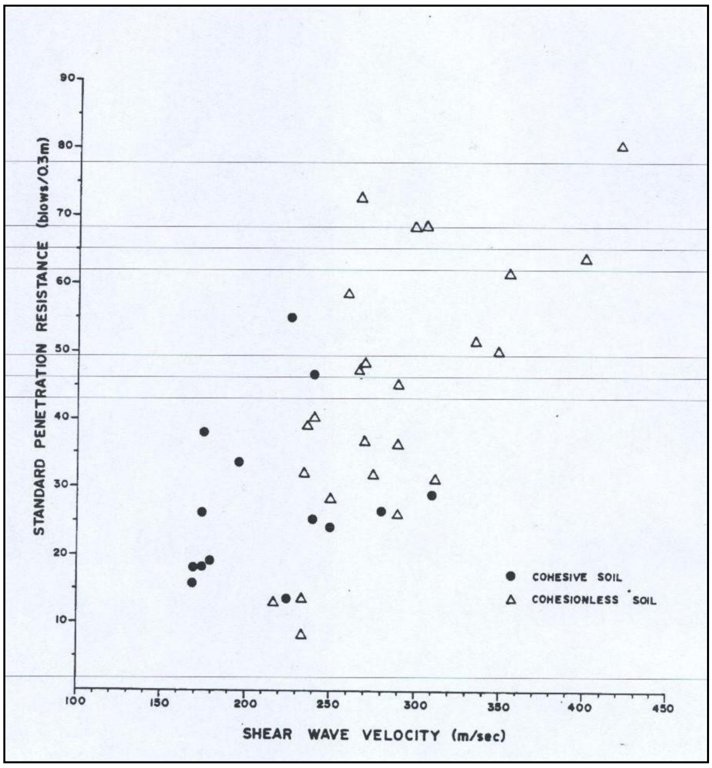


Figure 2.17 Variation of s-wave velocity with SPT (Fumal, 1987).

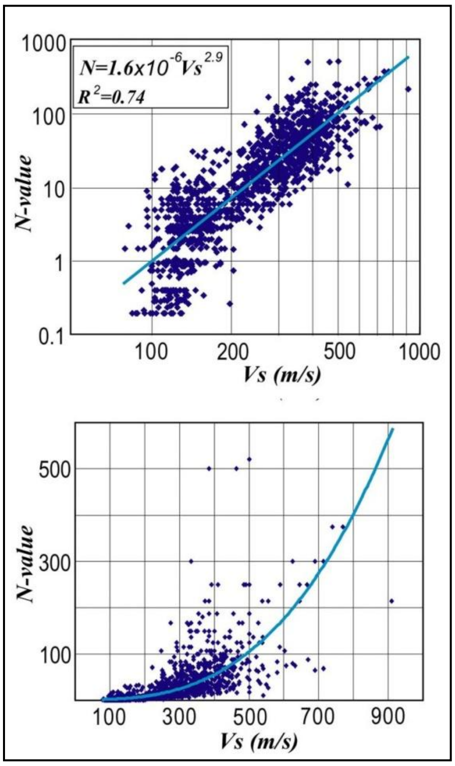


Figure 2.18 Cross plot of S-wave velocity and N-value measured at the same horizons on a log-log scale (top) and on the linear scale (Inazaki, 2006).

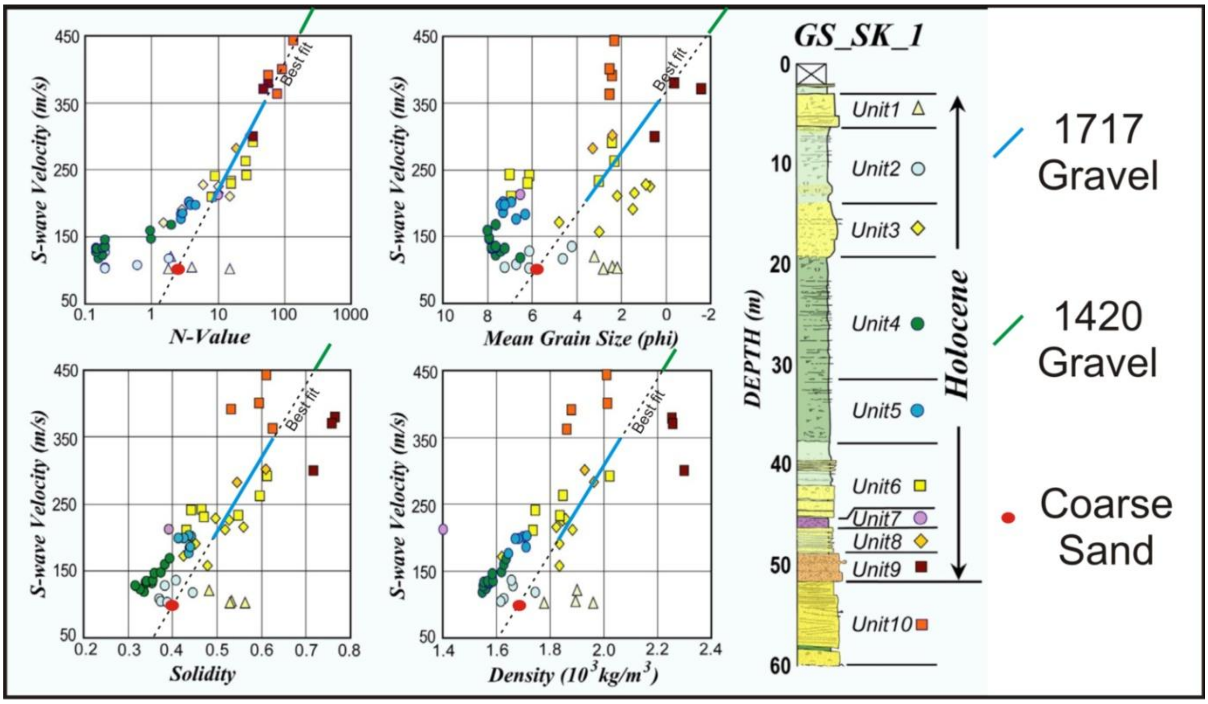


Figure 2.19 Relationships between S-wave velocity and N-value, mean grain size, solidity, and density. The triangle and rectangle shaped symbols coloured with red, orange and yellow represent coarse grained sediments such as sand and gravel. The stratigraphic column to the right shows the depth of each specific unit. The circles coloured in green and blue indicate silt, clay, and peat (Inazaki, 2006).

To attempt a correlation between s-wave velocity and other properties, a line of best fit was placed through the coarse grained sediments on each of the four graphs in Figure 2.19. As we are only dealing with coarse sediments, fine sediments on the graphs were ignored. Along this line of best fit, the S-wave velocity range for each unit can be plotted on to estimate possible geotechnical properties.

Table 2.5 Inferred properties of materials in the Whataroa Valley it should be highlighted that these are inferred values and may not accurately reflect the properties of the materials present at the site.

Unit	S-wave velocity range (m/s)	Inferred values			
		N-Value	Mean grain size (phi)	Solidity	Density (10^3 kg/m^3)
1717 Gravel	200 - 350	9 - 80	3.6 - 0.4	0.49 - 0.63	1.83 - 2.5
1420 Gravel	450 - 600	120 +	≤ 0.7	0.72 +	2.2 +
Coarse Sand	100	4	5.8	0.4	1.69

The mean grain size plot in Figure 2.19 can be used to see how successful this attempt was, as we can estimate the mean grain size from the insitu descriptions of the materials and compare the two. The s-wave velocity of the coarse sand plotted a mean grain size of 6ϕ, this would suggest a silt. The s-wave velocity range for the 1717 AD gravel plotted mean grain sizes that suggest very coarse sand to fine sand, when there are clearly many large boulders present in this unit. This suggests there are some inconsistencies with this attempt. The nature of the method used to collect the s-wave velocities average the data out too much to accurately gain a geotechnical parameter such as N-value, and given all of the factors previously discussed that can effect s-wave velocity, without knowing the actual materials specific texture, void ratio and saturation, and how it reacts to overburden depth, it would be very difficult to correlate with a known unit. Additional on site testing should be carried out if these geotechnical parameters are required.

However, the averaged s-wave velocities from the MASW surveys returned V_s30 values which can be used.

2.4.2 V_s30 values

A V_s30 value is the average S-wave velocity in the upper 30 m of a profile, it is a parameter commonly used to classify soils for earthquake design.

The MASW survey gave a series of V_s30 values along each survey line. Using these values in conjunction with the National Earthquake Hazards Reduction Program (NEHRP) – Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, and New Zealand Standard 1170.5:2004 – Structural Design Actions Part 5: Earthquake actions – New Zealand, we can classify the soils to help with ground motion predictions.

Table 2.6 Site class definitions. Parameters taken from NEHRP and NZS. It should be noted that the NZS takes the depth to rock into account when classifying a soil, NEHRP does not. As we do not know the depth to bedrock it will have to be excluded. (Building Seismic Safety Council for the Federal Emergency Management Agency, 2003) (NZS, 2004)

Site Class	Soil Profile Name	Average Properties in the top 30 m Soil Shear Wave Velocity, V_s (m/s)
A	Hard Rock	$V_s > 1500$
B	Rock	$760 < V_s \leq 1500$
C	Very dense soil and soft rock	$360 < V_s \leq 760$
D	Stiff soil profile	$180 \leq V_s \leq 360$
E	Soft soil profile	$V_s < 180$

Table 2.7 V_s30 values for the Whataroa terraces.

	Line 1	Line 2	Line 3
Min (m/s)	291.69	228.31	295.94
Max (m/s)	363.4	339.37	340.61
Average (m/s)	325.0782	274.5462	321.97

According to the table above V_s30 values of the soils at the site are all within class D, apart from the maximum value for Line One at 363.4 m/s. To be conservative we consider this to be in class D. This classification can be used to better constrain the predicted Peak Ground Accelerations (PGA) discussed in Chapter Three.

2.5 GPR – Ground Penetrating Radar

GPR was used to identify depth to bedrock. A description of the method, collection and processing parameters used in these surveys are specified in Appendix A. The survey locations can be seen on the Whataroa Valley Geophysical Investigations Map in Appendix B. The raw results of each of the lines and their coordinates can be seen in Appendix F.

The depth reached in all surveys was around 25 m. Bedrock was not seen in any of the surveys, therefore depth to bedrock is at least 25 m.

The majority of the survey lines did not show a lot of structure. Some showed a signs of planar features at 5 & 15 m depths, this could be interpreted the water table or a contact between two different gravel units. WHAT1 shows these two contacts clearly and is consistent with MASW Line Three.

WHAT0 and WHAT3 showed some extra features. The WHAT3 & WHAT1 profile interpretation can be seen in Figure 2.20 and Figure 2.21, WHAT0 is discussed in the Chapter Three.

WHAT3 showed signs of a series of gently north dipping reflectors. These have been interpreted as gravel and sand layers that have been progressively deposited, building the terrace northwards. This suggests the terrace is younging to the north which is consistent with the progressive thinning of topsoil in this direction seen in the testpits mentioned earlier.

To better constrain the water table or contact seen across the surveys at 5 m depth, WHAT8 which was located very near the river bank outcrop, was compared with MASW lines 1 & 2 and a photo of the river bank (Figure 2.22). The figures matched up very well, all showing the same major reflector at the same depth as the contact between the two gravels seen in the outcrop. This suggests the reflectors seen at similar depths in surveys across the fan could be interpreted as the gravel contact. However this is not to say that it is not the water table contact as well.

2.6 Summary

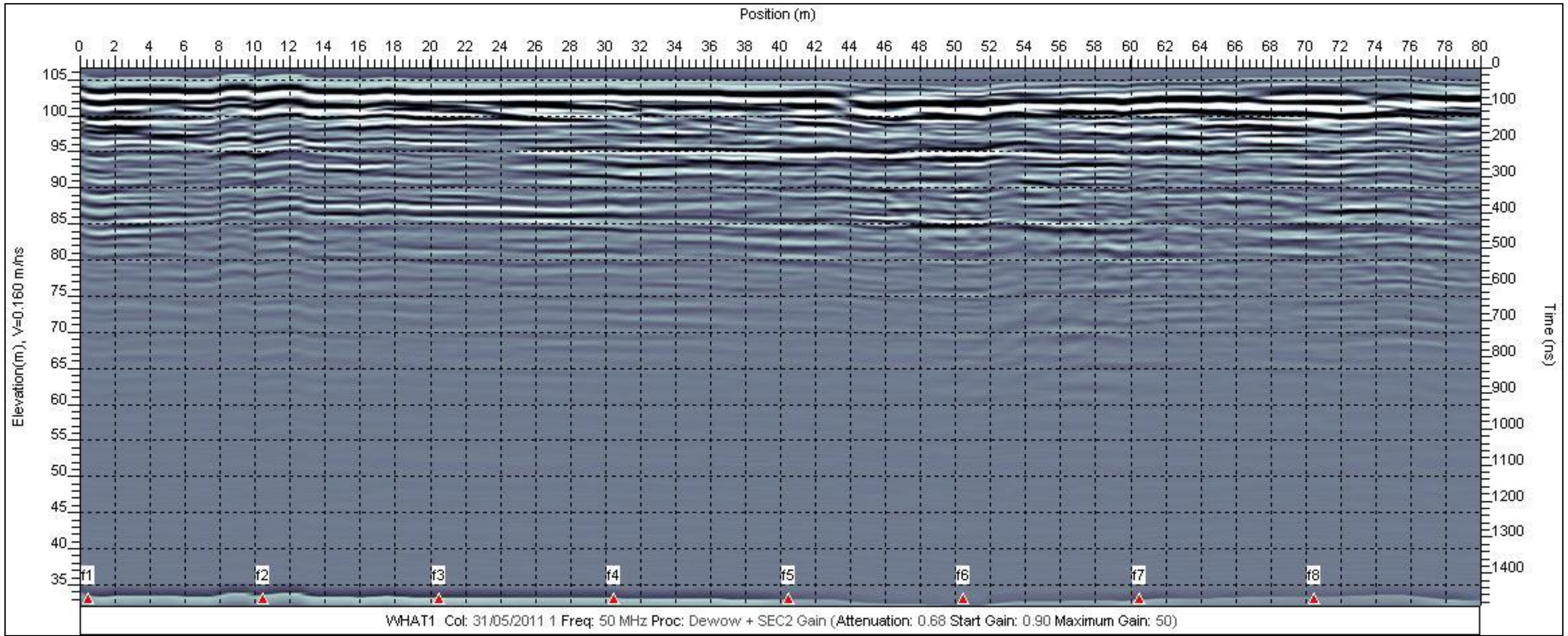
This chapter has provided an insight to the materials present in the Whataroa Valley. Although it has not provided a site specific investigation exactly where a drill rig will be placed, the data collected and the correlations made provide a tool for identifying geological units in future studies in the Whataroa.

The geophysical surveys have been correlated with the terrace edge identifying each unit's geophysical signal. And the testpits showed that the gravel unit present at the site is relatively homogeneous across the terrace, so the results gained from the survey could be analogous for other areas where that unit is close to the surface.

A detailed GPR survey prior to drill rig placement, coupled with these results could be beneficial towards understanding the near surface geology at a specific location.

Key results found from this chapter are:

- The inferred foundation support for the alluvial gravels is ~70 – 95 kPa. This is close to the requirements for NZS 3604 for a timber frame building. This suggests the gravels at the site are competent enough to support a temporary drilling structure and monitoring station, if not, minor remedial work can be done to bring it up to standard.
- Particularly to the north of the terraces, the testpits showed the presence of large sandbars and lenses. This material is weak and unsuitable for a drill pad setup.
- V_s30 values returned values between 228 and 363 m/s placing the soils in class D of the site class definitions of NZS 1170.5. This will help estimate the PGA in Chapter Three.
- GPR Profiling showed bedrock is at least 25m deep.



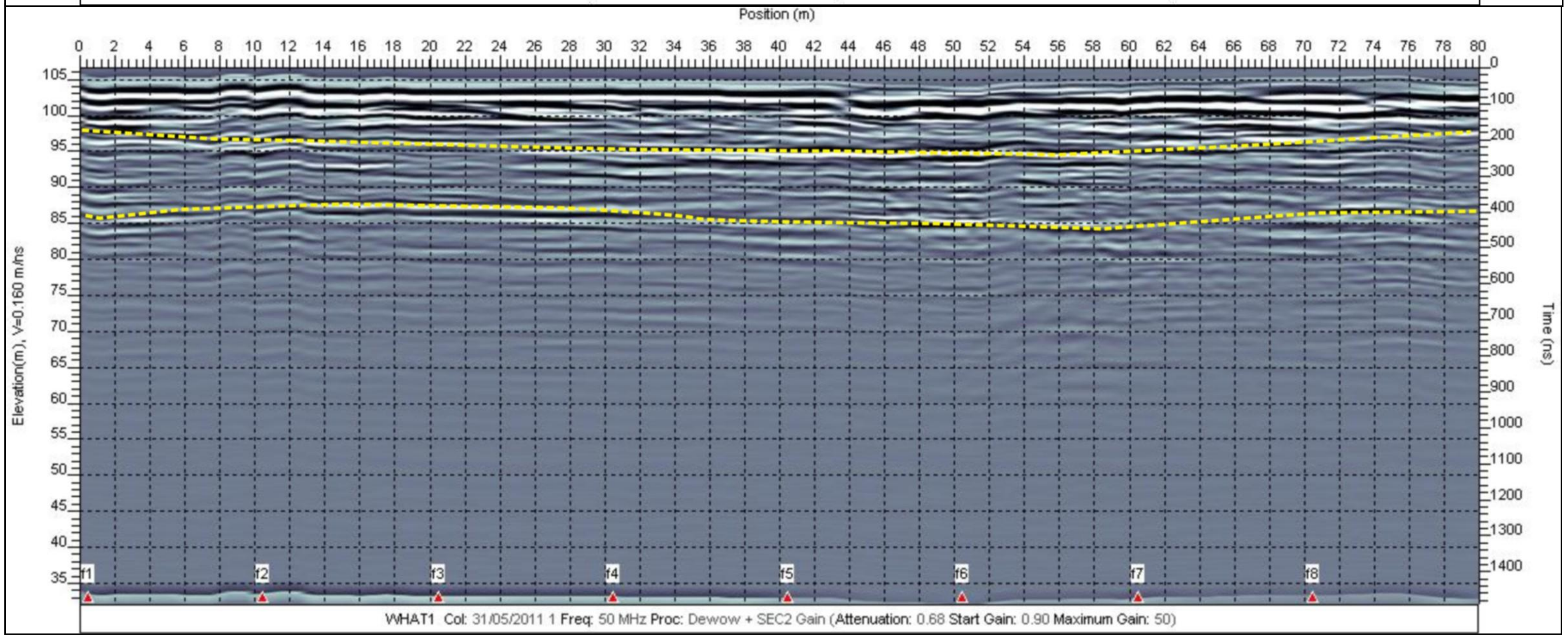
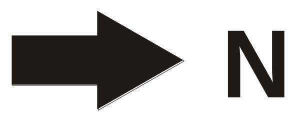


Figure 2.20 WHAT 1GPR line interpretation showing possible new gravel contacts at depth. This interpretation could fit with MASW survey Line 3 (Figure 2.12). This line also has a possible new gravel unit at depth.



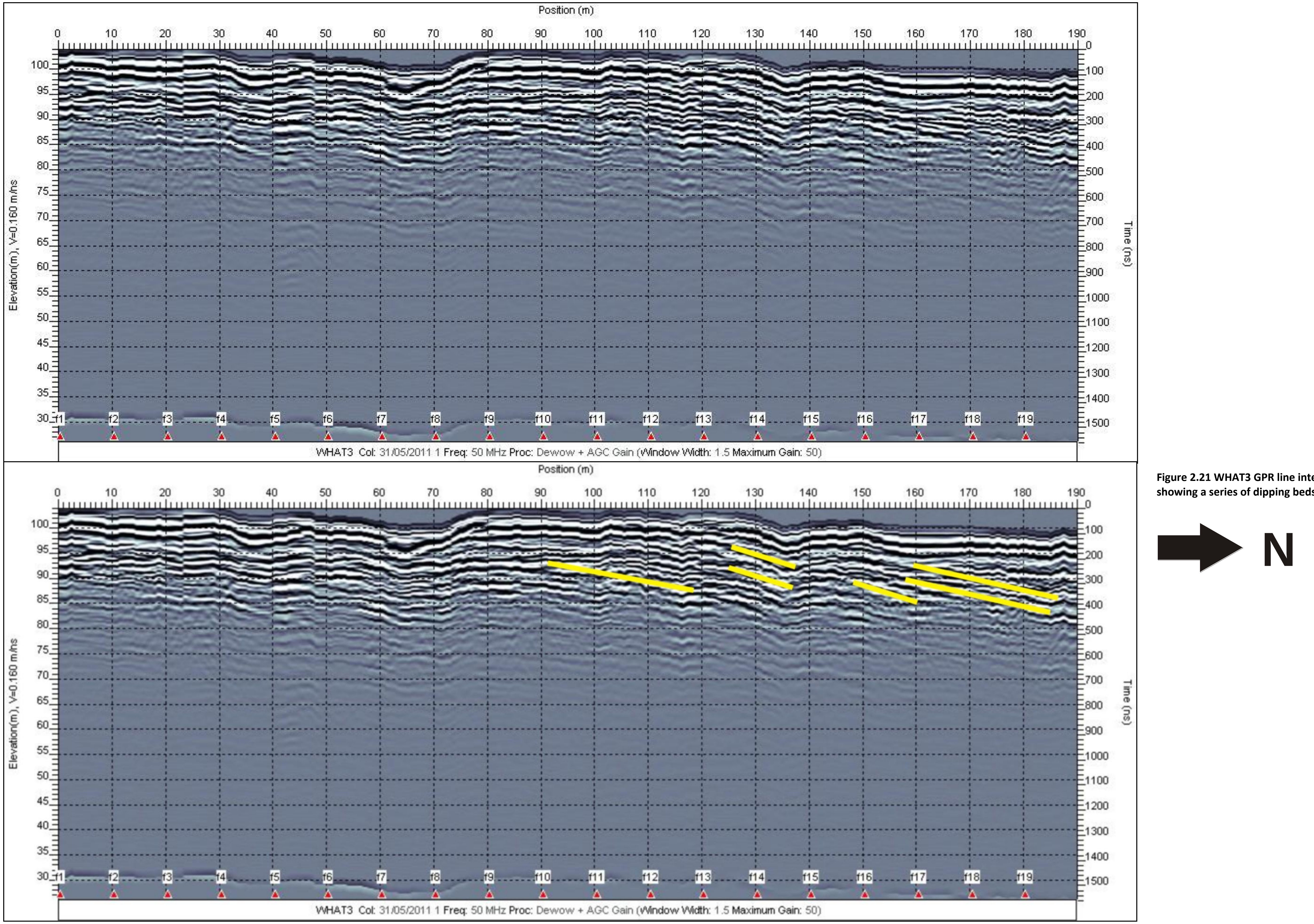


Figure 2.21 WHAT3 GPR line interpretation showing a series of dipping beds.

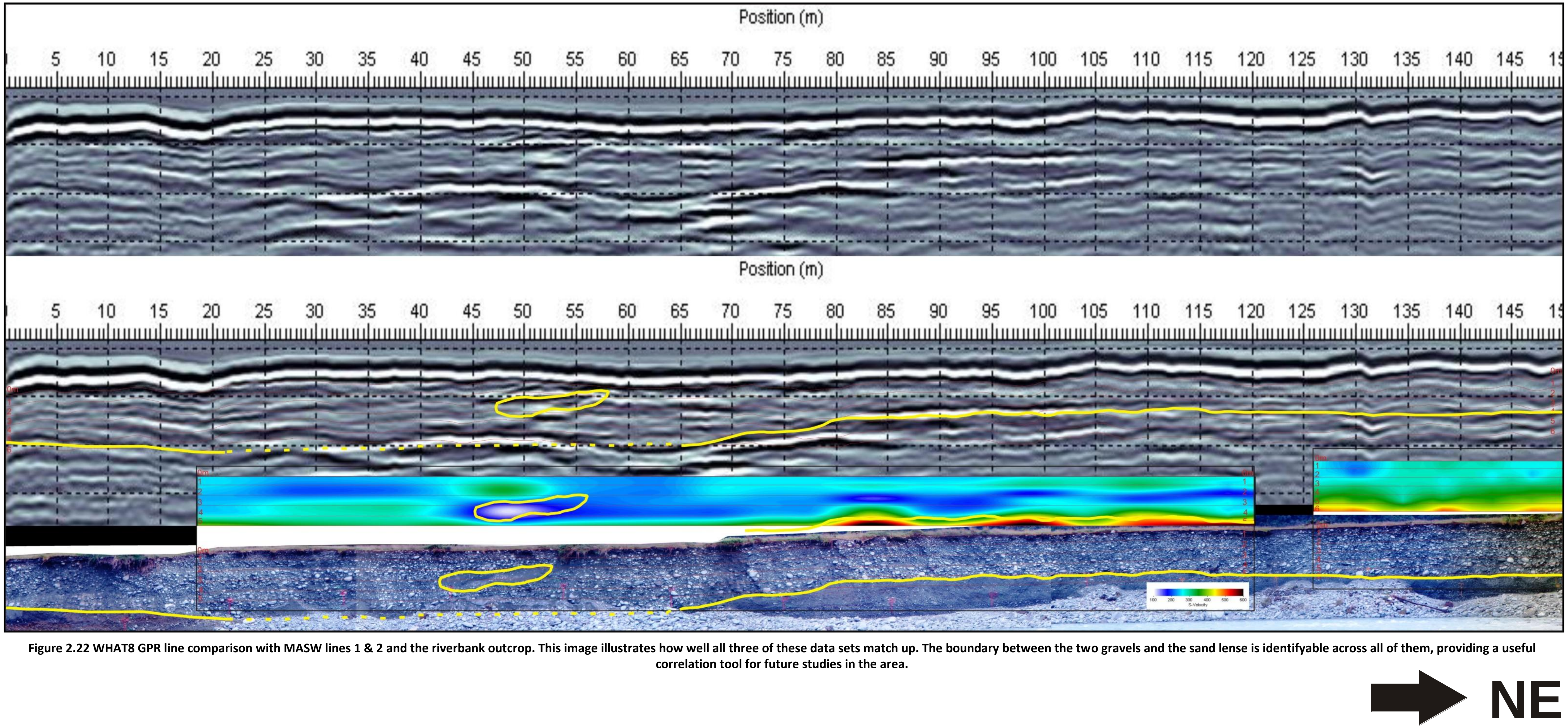


Figure 2.22 WHAT8 GPR line comparison with MASW lines 1 & 2 and the riverbank outcrop. This image illustrates how well all three of these data sets match up. The boundary between the two gravels and the sand lense is identifyable across all of them, providing a useful correlation tool for future studies in the area.

3 Hazard Assessment of the Lower Whataroa Valley

3.1 Introduction and Methods

Several methods (outlined in Chapter Two) including mapping, GPS measurements, GPR and MASW, along with desktop investigations studying historical images, and rainfall and river discharge data were used to identify the hazards posed to an Alpine Fault drilling operation based in the Whataroa Valley. Here we assess the risk posed by each hazard and calculate probabilities to identify their relative return periods.

3.2 Flooding and Inundation

The Whataroa Valley receives over five meters of rain per year, often in heavy rainfall events of over 100mm over a 24 hour period, occasionally reaching 250-300mm over a 24 hour period. This can lead to very high river levels and activation of ephemeral streams. Consequences of high rainfall in this area include river aggradation, landslides, high river levels and/or local surface ponding. Additionally, periods of heavy snow-melt contribute to high runoff.

The maximum recorded discharge in the Whataroa since records began in 1989 was 3952 m^3/s on the 9th of January 1994 (DTEC Consulting LTD, 2002), with the highest river level recorded at 5039mm on 13th December 1995 (WCRC, 2011). Below are the calculated discharges for various flood return periods.

Table 3.1 Calculated Flood Discharges and Return Periods (Bowis & Faulkner, 2000)

Return Period (years)	Discharge (m^3/s)
1	2 822
5	3 403
10	3 876
20	4 330
50	4 918
100	5 358

Flooding of the 1717 AD and 1620 AD terraces by the Whataroa River is unlikely due to the high terrace edge on the southern river bank. The 1717 terrace is about 9-10 m above river level and the 1620 terrace ~14 m. At the north end of the terrace, the water level is eight metres below the terrace surface, apart from a very small lower section at the northern tip that was active river bed ~60 years ago as indicated from the 1948 aerial photos (Appendix H). To quantify the likelihood of inundation of the terraces we estimate the discharge needed to over top each surface. Discharge (Q) can be calculated using the following equation:

$$Q = VA$$

V = velocity (m/s),

A = the cross-sectional area (m^2).

The area was measured with a cross section extracted from the LiDAR data. Velocity was calculated using the Manning Formula:

$$V = 1/n\ R^{2/3}.S^{1/2}$$

n = the Gauckler–Manning coefficient (co-efficient for determining the roughness of the river bed).

R = the hydraulic radius (m).

S = the slope of the water surface.

The hydraulic radius is calculated by:

$$R = A/P$$

P = the wetted perimeter. This was calculated using the cross section extracted from the LiDAR

The bed roughness was estimated at 0.05, and the slope was calculated from the water surface on the LiDAR to be 0.0028 and it was assumed to be the same at all discharge rates. The resulting discharge rates are below.

Table 3.2 Discharge needed to overtop each terrace surface.

Surface	Discharge (Q) (m^3/s)	Return Period (years)	Annual Probability (%)
1717	7782	~9000	1.1E-4
1620 degradation surface	9682	~240000	4.2E-6
1620	17208	~1.3E+11	7.7E-12

All of these discharges are well above the 100 year flood period of 5358 m^3/s. To calculate and compare the return period for events of this magnitude, the published return periods were plotted on a graph and extrapolated to discharge thresholds for terrace overtopping. The values in this calculation were estimated. Although there are some uncertainties inherent to this method, the resulting return periods are very high compared to the average return time of major earthquakes in this region, which is discussed in Section 3.5.5. We thus conclude that the inundation hazard to the terrace surfaces with the present channel geometry present a much lower annual probability than the next Alpine Fault earthquake (0.5-2% (Yetton, Wells, & Traylen, 1998) (Rhoades & Van Dissen, 2003)), after which, the landscape of this area will dramatically change, and possibly be completely resurfaced due to large sediment input. The earthquake hazards are discussed later in this chapter.

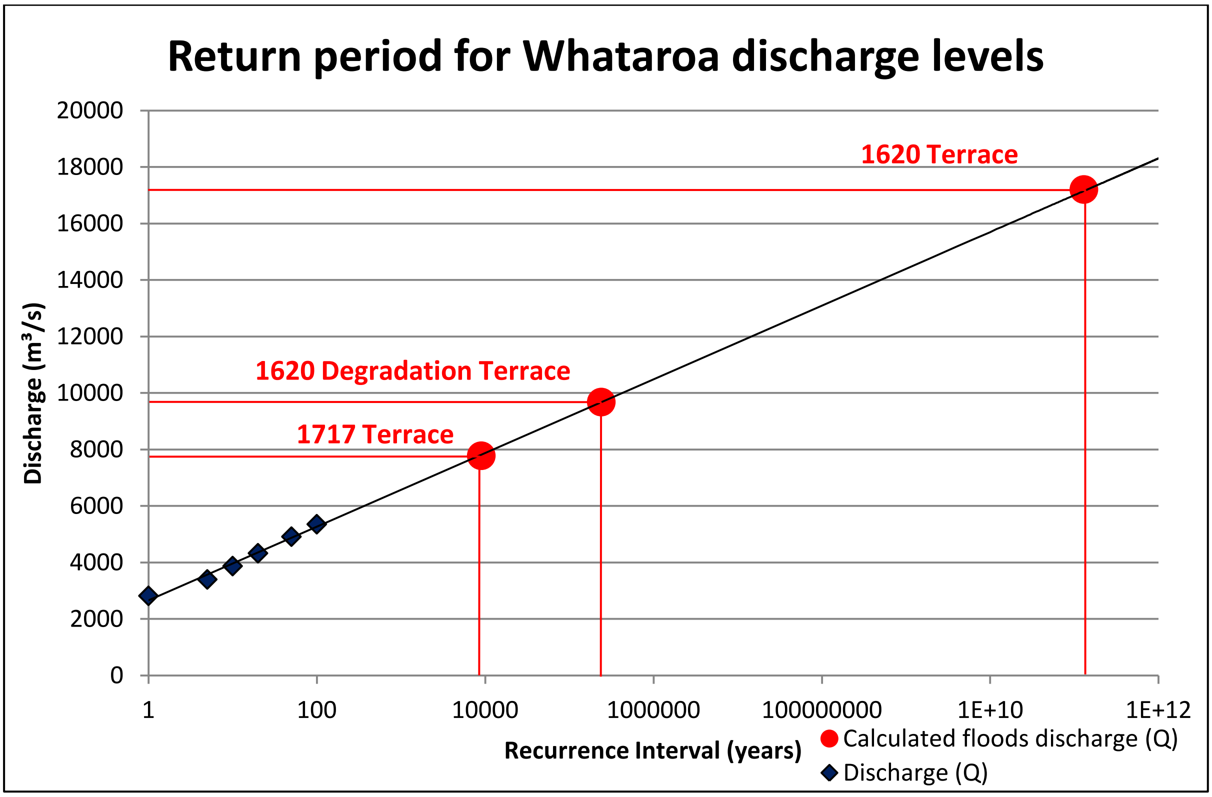


Figure 3.1 Published recurrence intervals and calculated food discharges to overtop Whataroa terraces. The graph illustrates the extremely low probabilities of the Whataroa surfaces being overtopped by the Whataroa River. These values could be calculated more accurately using a model such as HEC-RAS (US Army Corps of Engineers, 2008).

This estimation is based on a fixed channel geomorphology, it is almost certain that should one of these flooding scenarios occur, the loose erodible material of the terrace is likely to be quickly eroded away, changing the morphology of the channel making inundation less likely to happen. The possible effects of channel migration are discussed later in this chapter.

Observations indicate that localised surface flooding is more likely to affect drilling operations. The majority of the terrace surface does not have any flowing water on it, however, despite being composed of well draining loose gravels, there are a few areas that have ponded water. After/during periods of heavy rainfall, these areas grow considerably in aerial extent, as indicated from personal observations throughout 2010-2011. There are also many areas that have ephemeral flowing streams or large swamps, illustrated in Figure 3.2 below. During a period of constant rain from 5 – 14th of July 2011 (ranging from 12.7 – 47.5 mm/day), all the areas that are prone to becoming swampy were mapped with the GPS unit, this map is included in Appendix B, and is used in the hazard summary map at the end of the chapter, this will be important for avoiding inundation of a drill site.

Figure 3.2 An example of one of the ephemeral channels in both Wet and Dry Conditions. Highlighting how easily areas of the terrace can become inundated.

3.3 Erosion and Stream Migration

Upon completion of the DGPS Survey in June 2010, and in comparison with the Google Earth images, dated 23 October 2002, it was obvious that the river bank had substantially migrated westward from 2002 to 2010, up to 50m at some positions. Based on these measurements, we estimate a maximum stream bank lateral erosion rate of ~6 m/year.

On the 2nd of June 2011, nine months after the LiDAR survey was flown (2nd of September 2010) another GPS survey of the south bank was recorded showing a maximum of 35m erosion since the previous September, greatly exceeding the 6 m/year average from the previous eight years. All of this erosion is thought to have occurred in a few days over a period of storms in early January.

An old aerial photograph (dated 13/4/1948) was obtained from GNS Science. In this the river bank was 80m away from its position in 2002. This gave a series of erosion rates as follows:

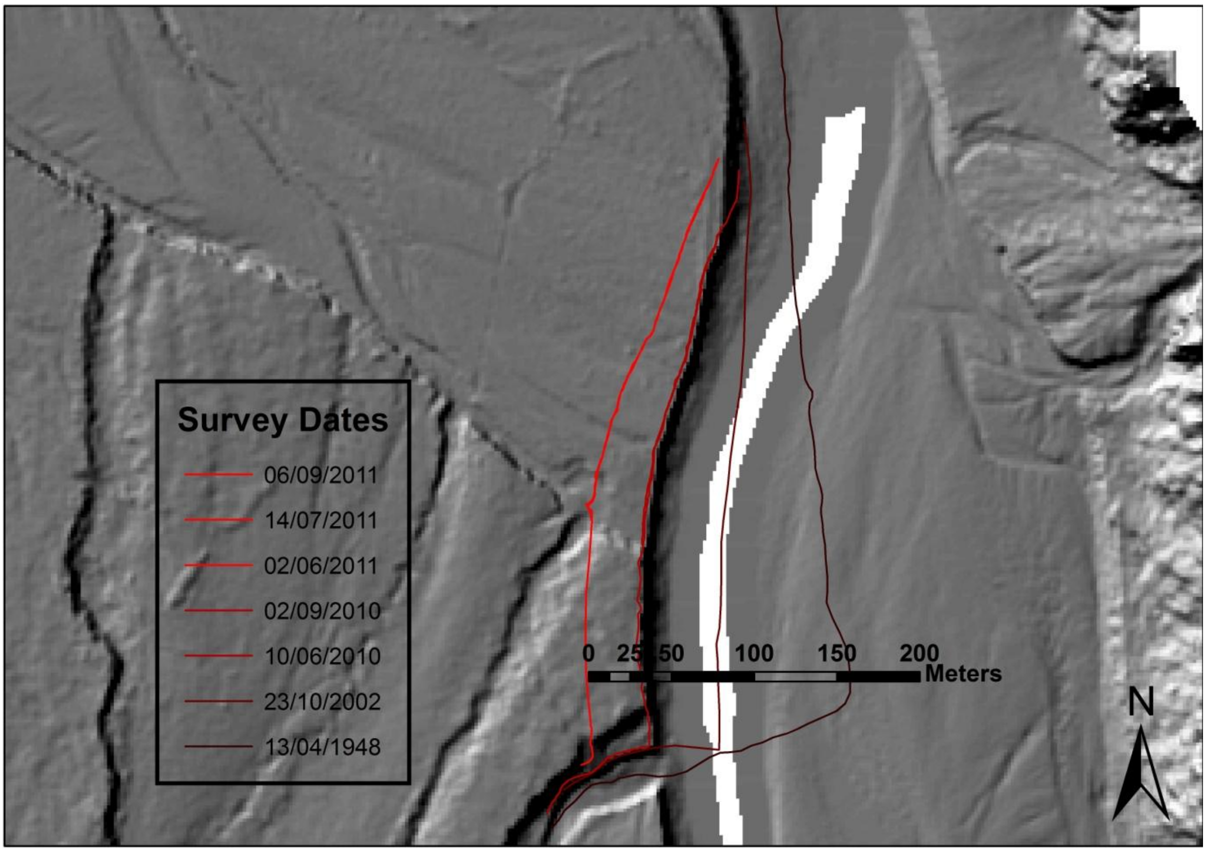


Figure 3.3 Progressive Erosion of the South Bank of the Whataroa Terraces.

Table 3.3 Averaged Yearly Erosion Rates

Time Period	Years	Erosion (m)	Rate (m/year)
1948 - 2002	54	80	1.48 ± 4.5
2002 - 2010	8	50	6.25 ± 4
Sept 2010 - June 2011	~1	35	35 ± 2

This table highlights the high degree of variability in the ‘rate’ of lateral channel erosion. It shows an increasing trend of higher riverbank incision rates over the last ~60 years. However there is a large gap without images or surveys of the river and riverbank locations between 1948 and 2002. It is likely that the river has migrated east and west over that time.

Errors involved with the exact positions of the river bank with historic aerial photos ranged depending on the resolution of the photo. The 1948 photo had an error of ±1.5 m, the 2002 photo had an error of ±3 m and the 2010 photo had such high resolution that the thickness of the line used to mark the river bank on determined the error at ±1 m. The GPS unit used had an error of about 0.5 m however the thickness of the line boosted that up to ±1 m.

The errors are minor when compared to the scale of lateral erosion.

I document a number of factors considered to identify the reason for the apparent increase in erosion rate.

3.3.1 Hydrological Factors

Rainfall, river level and flows were interrogated to help identify the erosion mechanism and the nature of its frequency. Figure 3.4 is derived from data courtesy of the West Coast Regional Council (WCRC), they have provided rainfall data dating back to 1989 and river level flow data dating back to 1985.

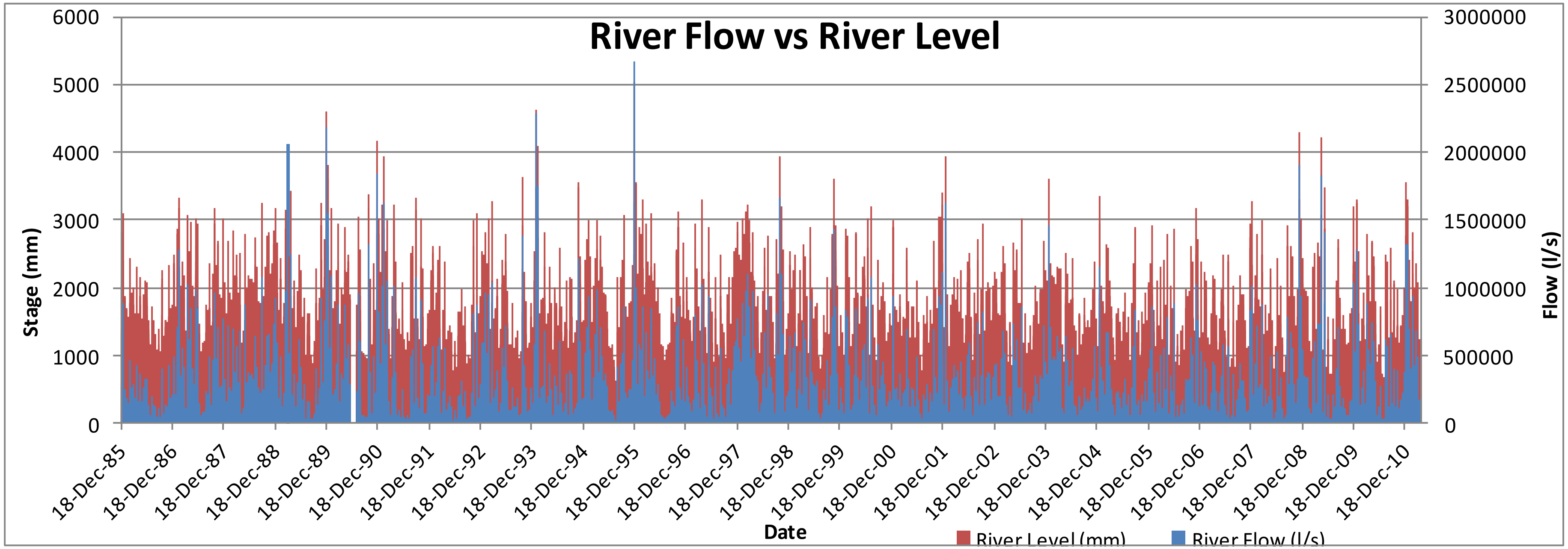
The first graph shows river level and flow plotted together, and the second shows river flow and rainfall. For investigation into the erosion of the south river bank, only river flow will be used, as the first graph illustrates that river level and flow are directly proportional to each other so there is no need to include both, and rainfall data does not take into account rain falling in the far reaches of the catchment or discharge from snowmelt as this will be a substantial contributor to river flows at certain times of the year. This is evident in the graph as the spikes in the data do not match up.

The average, minimum and maximum flows since 18th December 1985 are as follows:

Average: 131732 l/s

Maximum: 2664455 l/s – 13th December 1995

Minimum: 16322 l/s – 7th August 1995



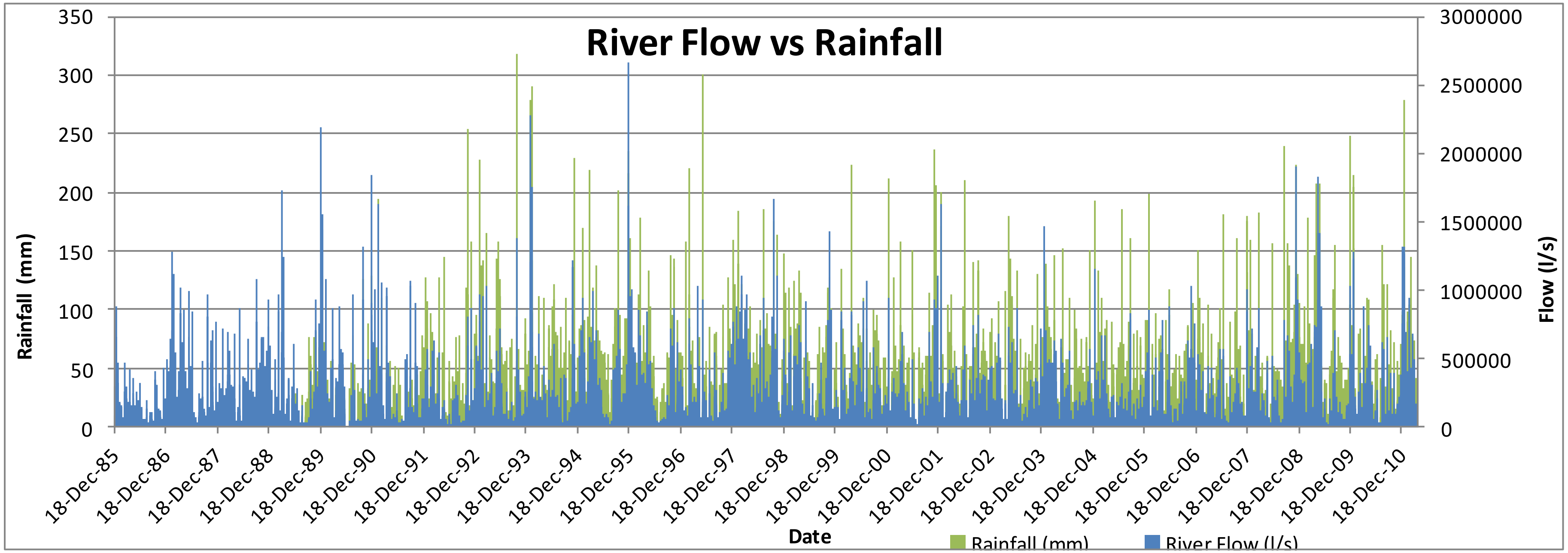


Figure 3.4 River flow and level data from site 89301 and rainfall data from Site 303411 at the Whataroa State Highway Bridge (WCRC, 2011). The top graph shows a strong relationship between river flow and river level. Whereas, the bottom graph displays no relationship between river flow and rainfall. This suggests river flow is the appropriate parameter to use to analyse riverbank erosion.

Three thresholds were arbitrarily chosen to investigate the frequency of large storms, flow events of 500000 l/s and above, 750000 l/s and above, and 1000000 l/s and above. This data was filtered out and plotted on a separate graph. “Marker” lines representing dates of measured riverbank locations were inserted for analyses (Figure 3.5).

There does not seem to be a strong correlation between high river flow events and erosion. Pre-2002 there is clearly a larger concentration of more extreme river flow events than in the last decade, and they don’t seem to have caused the major river migration seen recently.

During the short period between June 2010 and July 2011, there was only one event that exceeded 1000000 l/s, compared to 11 between 2002 and 2010, yet both periods had comparable amounts of erosion, 35m and 50m respectively.

The lack of a clear correlation between discharge and stream bank erosion rate indicates additional factors are important in dictating the stream bank erosional processes at this site. To confirm this I attempt to normalise cutbank erosion to a function of $m/m^3/s$, essentially how much erosion occurs per unit of discharge. Mean annual discharge rates were calculated (Figure 3.7). I attempted to estimate the discharge rates for the missing data between 1948 – 1985 by matching obtained Whataroa Valley rainfall and river flow data with data at another station downstream, deriving a function showing a relationship between them, then projecting the data back in time to the beginning of the downstream data in 1949. This data is shown in Figure 3.6. It does not show a strong relationship. This combined with the weak relationship between rainfall and river flow in the Whataroa Valley previously outlined suggests there is too much uncertainty involved with this method. Therefore data for the years prior to 1986 had to be excluded.

Figure 3.7 shows a drastic increase in the amount of erosion per unit discharge, whereas the mean annual discharge continues to fluctuate. This suggests hydrological factors are not influencing channel migration.

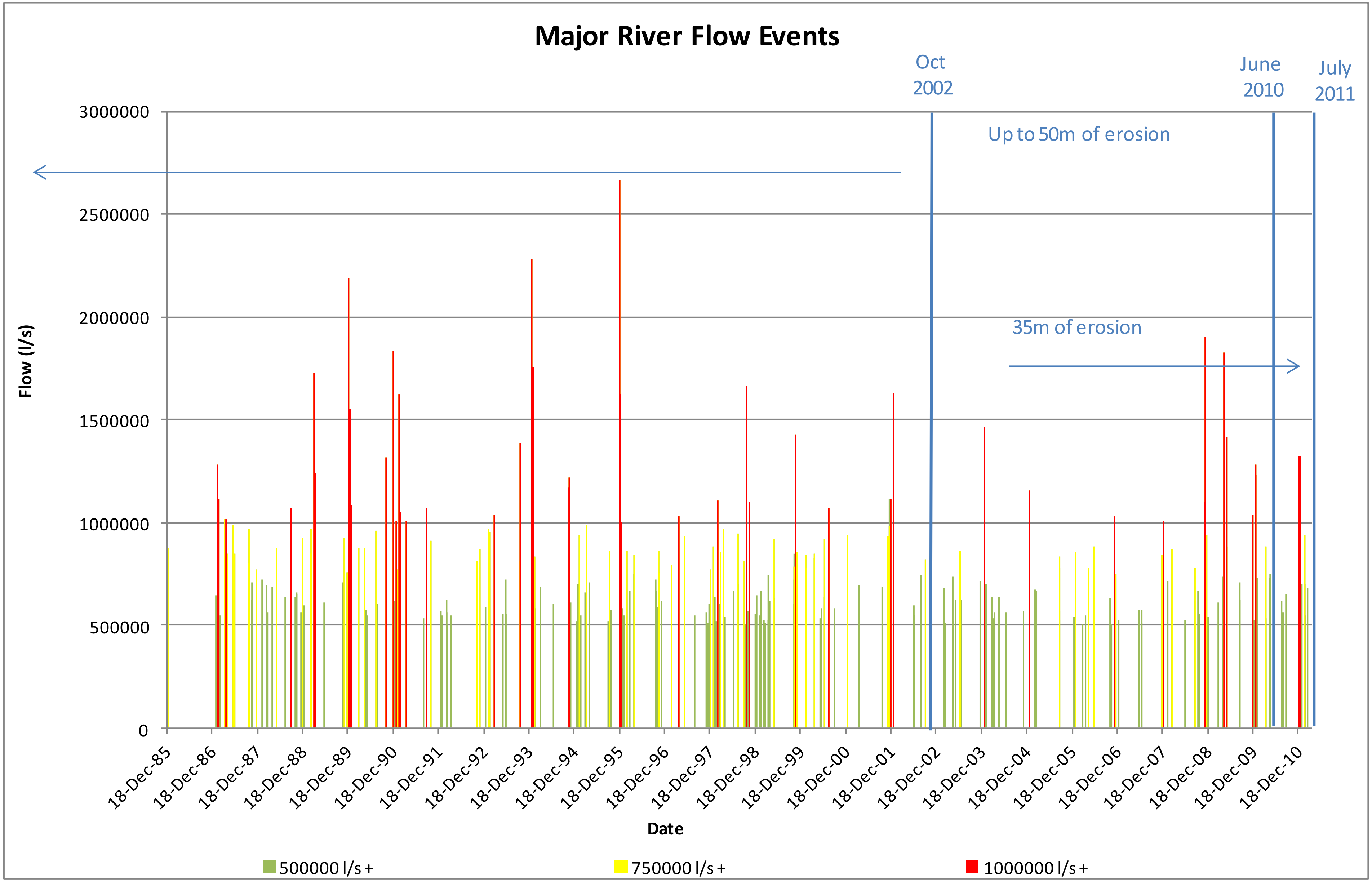


Figure 3.5 Major river flow events with markers indicating the dates we have measured river bank positions showing the time frames and the number of large flow events in which the various amounts of erosion has occurred.

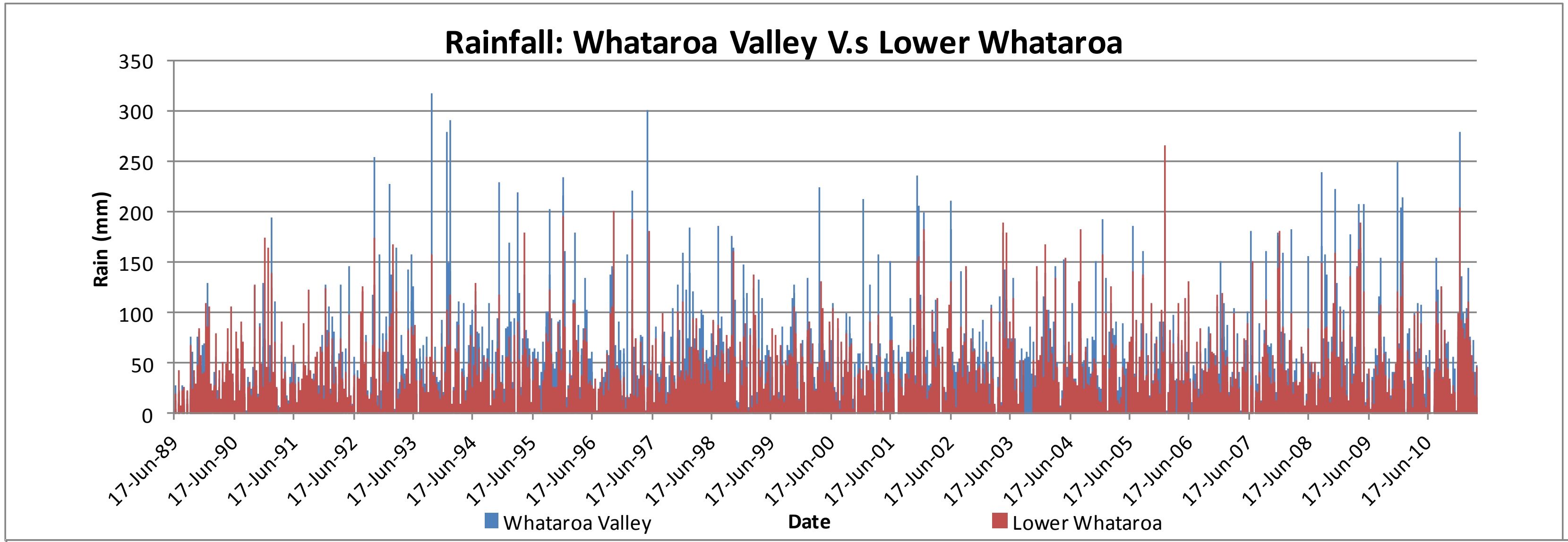


Figure 3.6 Attempted correlation between the Lower Whataroa and Whataroa Valley. The graph does not show a strong relationship between the two data sets.

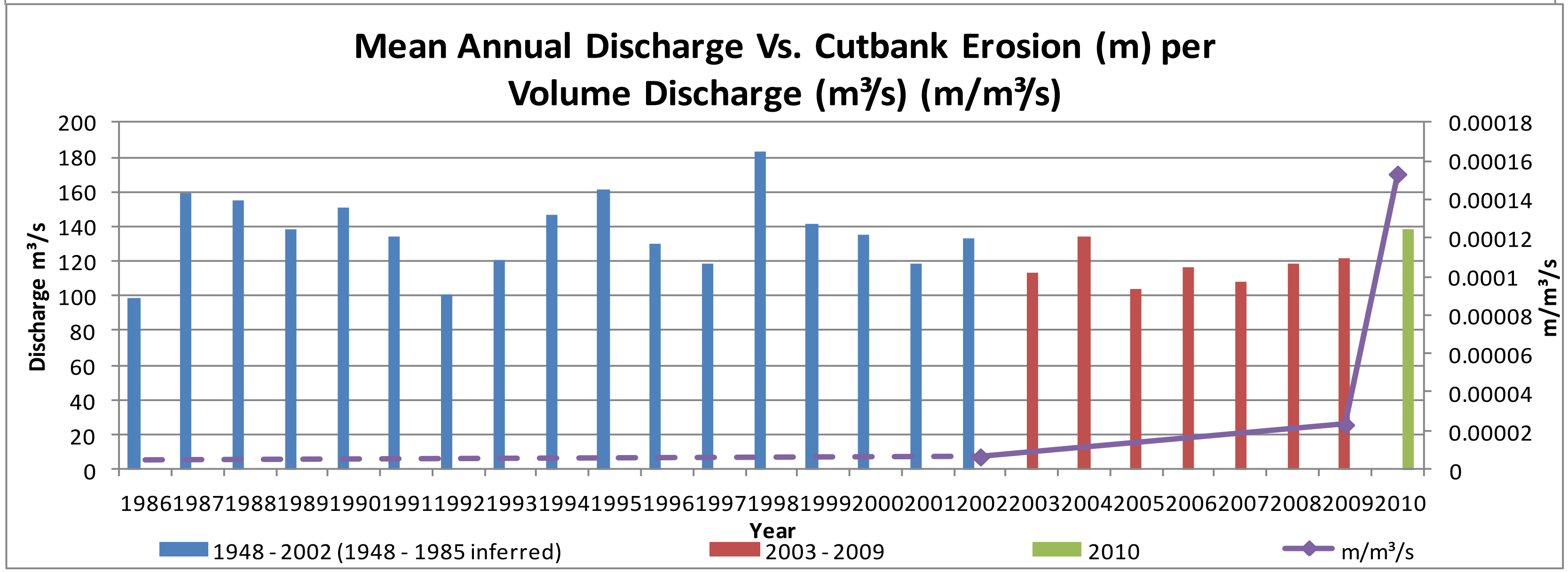


Figure 3.7 Mean annual discharge Vs. cutbank erosion per volume discharge ($m/m^3/s$). The amount of erosion per unit discharge drastically increases in recent years, however there is no trend or apparent increase in discharge.

3.3.2 Increased Curvature of the River Bend

Assuming a homogeneous substrate, constant channel width and constant flood velocity, a stream curve will migrate according to the formula:

$$V^2/R$$

Where V is velocity and R is radius of curvature. If V is roughly constant in floods, R will be the governing variable, therefore the sharper a bend is, the faster it erodes at any given flow rate (Francis, 1971).

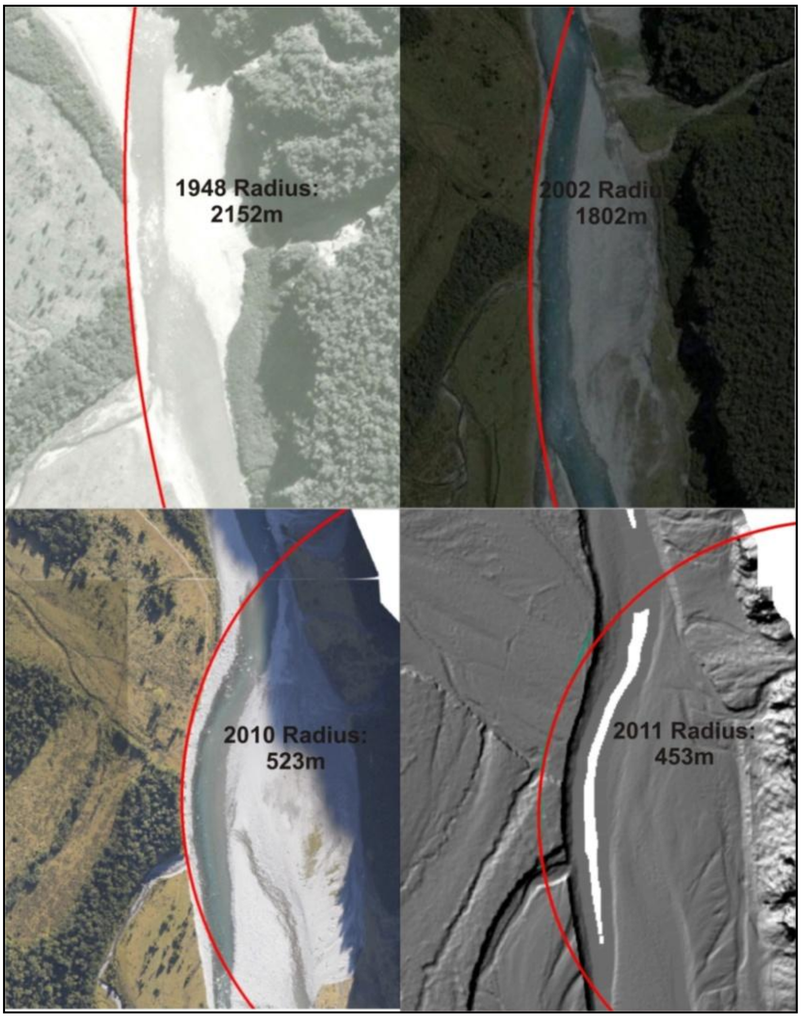


Figure 3.8 Gradual decrease in curve radius over time.

A best fit circle edge was put through the line of the river bank on each of the aerial photos, and the 2011 GPS data to derive series of radiuses (Figure 3.8). The increasing stream bank incision rate coincides well with the decreasing radius, (Figure 3.9). The radius of the river meander gradually gets tighter and tighter over time. This suggests the increased erosion rate is due to the bend getting tighter, providing a positive feedback loop. As the curve gets tighter it has more power to erode and the more it erodes, the tighter it gets. This is because as the angle of the river bank becomes more acute to the downstream direction of the river, the velocity of the water on the outside of the bend increases, increasing the shear stress acting on the stream bank.

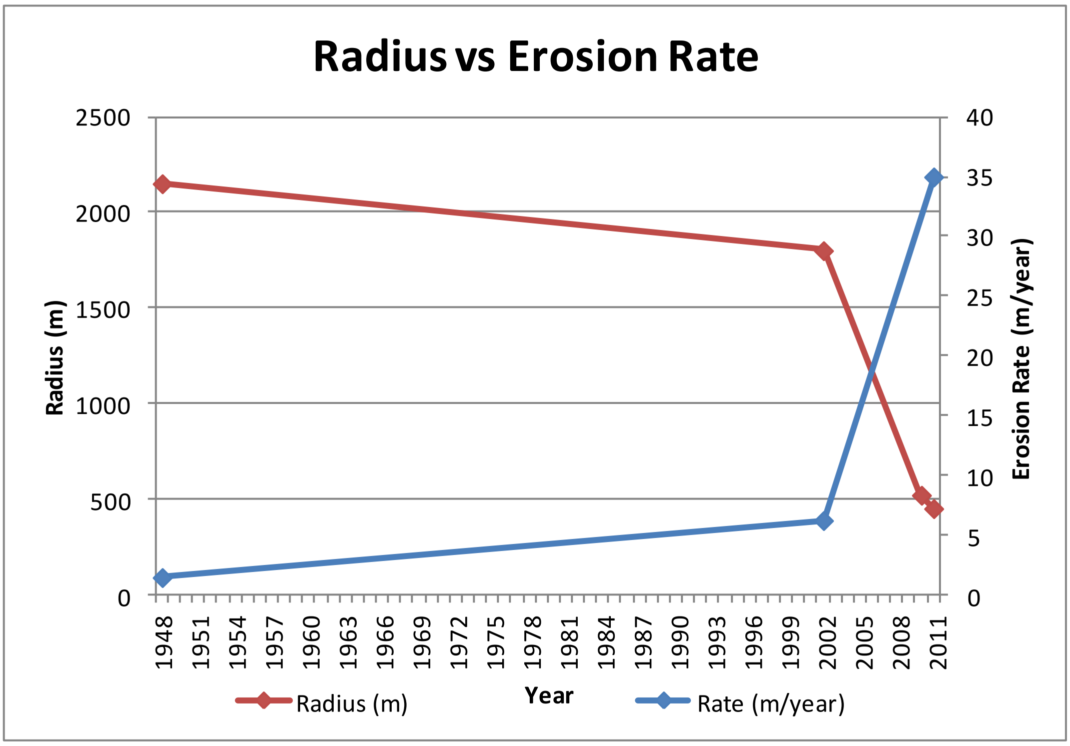


Figure 3.9 River curve radius vs. erosion rate showing a strong correlation, as the radius decreases, the erosion rate increases.

3.3.3 Sediment Input Controlling River Migration

The 100m high, 10000 year old (McSaveney, 2002) terraces to the east are completely composed of gravels. There a number of streams and tributaries running off these cliffs depositing material into the river, there is also ongoing rock fall, like the example shown in Figure 3.10, also acting as a sediment supply.

Figure 3.10 100m high gravel terrace on the east side of the river valley entirely made of gravels.

This input could be moving the river westward. The size of these cliffs, at ~100m high, will also have a negative feedback effect on the river. If the river was to migrate east and start eroding into these, it is possible that the volume that would be injected into the system could be enough to push the river back, providing a bias for the river to migrate to the west side of the valley.

Upon investigation into erosion of the river banks up stream of the site, it is evident that the river has eroded into the east side at least once since 1948 (Figure 3.12). The position of the river in the 1948 aerial photo relative to where the erosion occurred suggests it was very soon after the aerial photo was taken. The volume of sediment that was injected into the system was calculated and compared with the volume of sediment eroded on the opposite side of the river since 1948 (Figure 3.12).

East Terrace:

River Level: 93m

Elevation: 102m

Area eroded: 116979m^2

Volume: 1052784m^3

West Terrace:

River Level: 93m

Elevation 202m

Area eroded: 3775m^2

Volume: 367875m^3

The volume of the small scallop in the West terrace is equivalent to about 35% of the volume of sediment removed from the East terrace (Figure 3.12). The relatively sudden input of this sediment could have triggered the river to start migrating eastward to where it is now. The fact that the water "outlet" directly up stream has barely changed (Figure 3.11) since 1948 supports this, as the flow has been coming from the same direction the entire time.

Figure 3.11 Comparison between 1948 and 2002 directly upstream of the erosion area showing relatively unchanged river dynamics. This could suggest it is something downstream of this point that is causing the increased erosion.

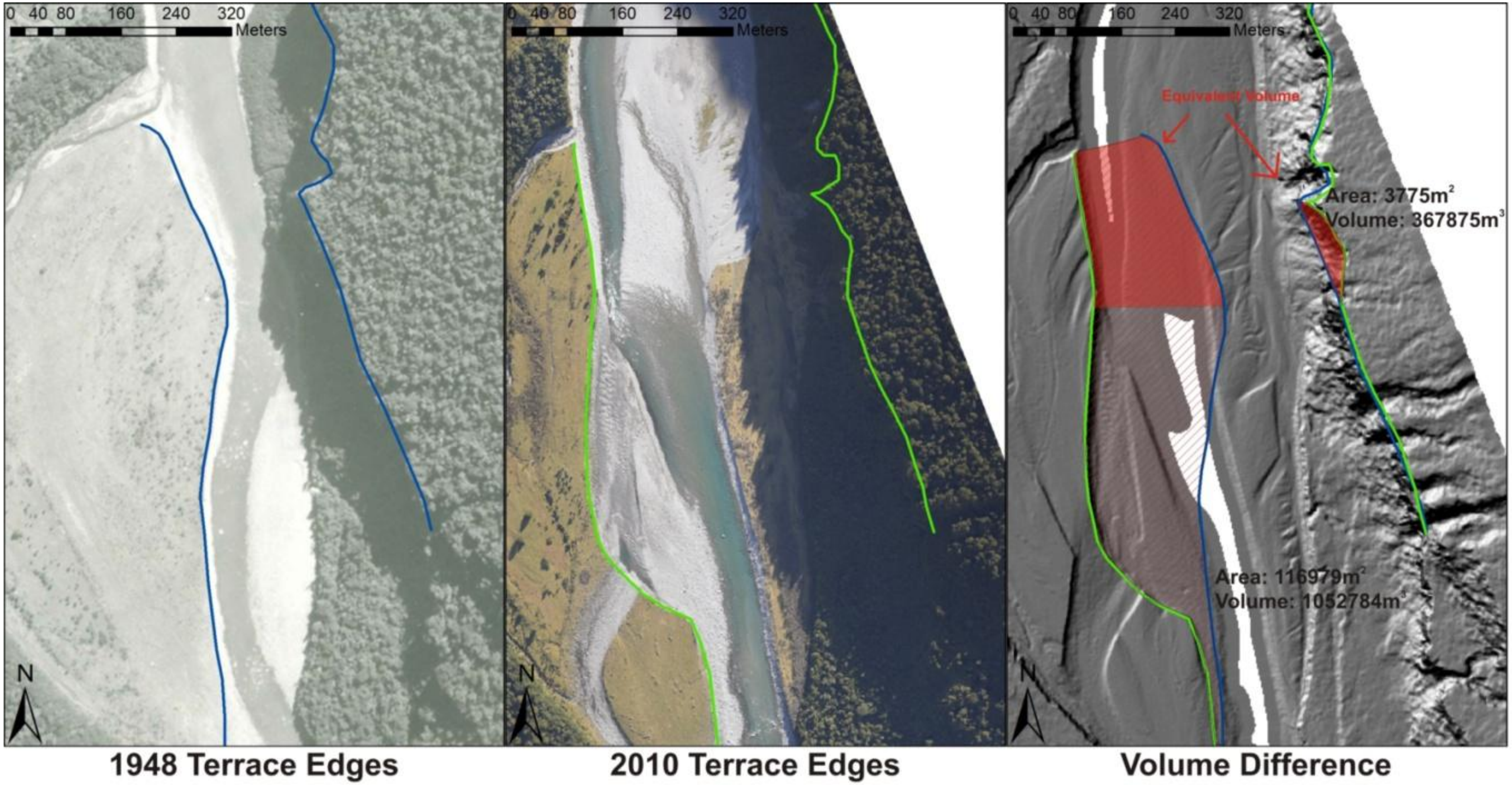


Figure 3.12 Volume vs. area comparison of the east and west terraces. This also shows the scallop eroded out of the east terraces since 1948. This is possibly a trigger for sending the river to the west where it is currently eroding into the 1620 and 1717 terraces.

3.3.4 General Erosion Mechanism

Failure of material from the top of the riverbank causing small scale migration of the bank edge occurs constantly. This is evident from the continual fall of new trees and shrubs into the river that is documented on every trip to the site (Figure 3.13 A). This material accumulates at the bottom of the bank. The smaller material is then removed by fluvial entrainment leaving the larger boulders behind. Some of these boulders measure up to 6.5m across, although as the largest in situ boulder in the riverbank only measured one metre, the much larger ones are likely sourced from upstream. As these larger boulders accumulate they act as natural rip-rap, protecting from scour during small or moderate rainfall events, and provide support for the bank and slowing down the process of slumping. This creates a period of stability.

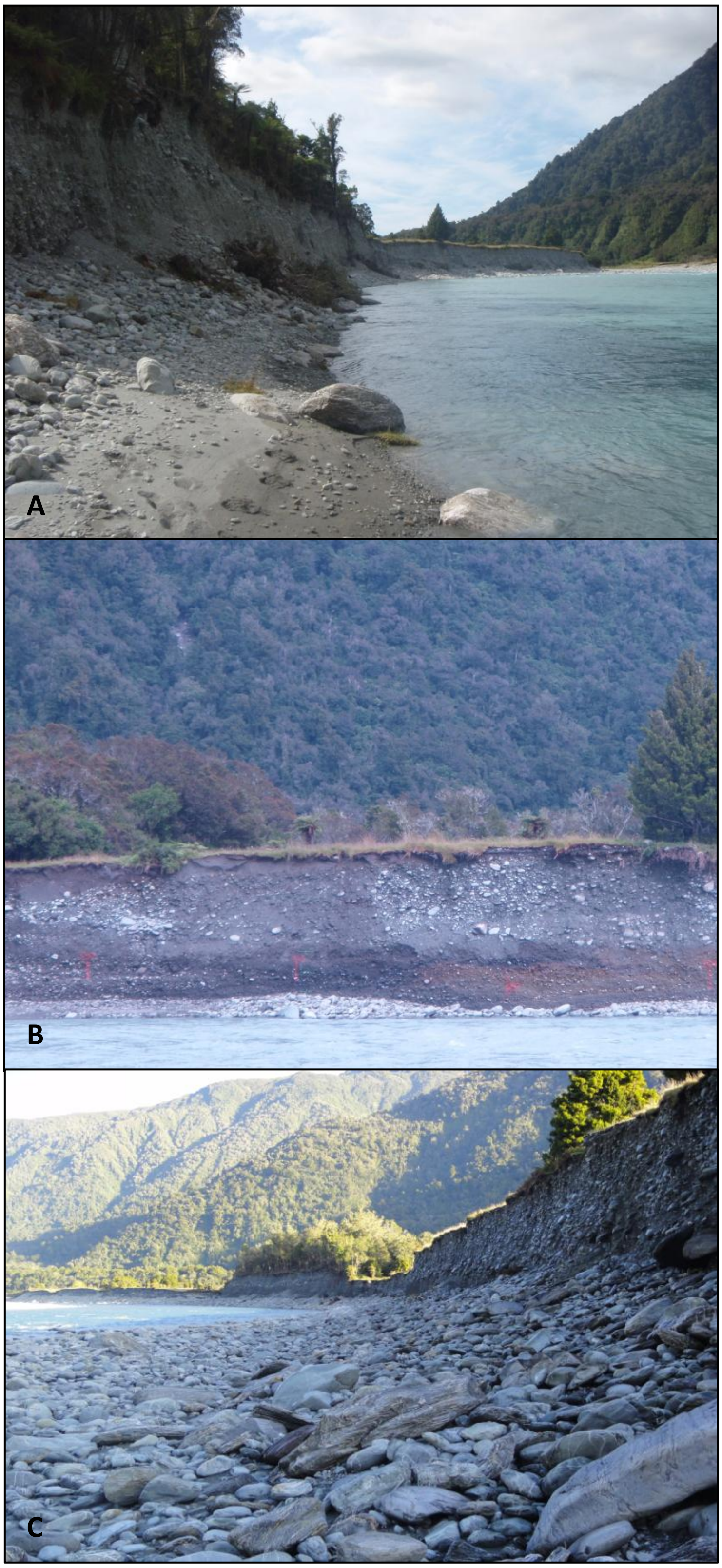


Figure 3.13 A. New Shrub Falling onto the River Bank. B. Exposed river bank after a heavy rainfall and erosion period. C. Built up natural “rip rap”

After a heavy rainfall event causing high river levels and enough stream power to move this larger material, the river bank is left exposed and unsupported (Figure 3.13 B), allowing material to collapse to the base of the river bank, and the process begins again. However, if the rainfall event persists or there is another significant event in short succession, the exposed cliff will not have built up protection and will be subject to scour, greatly increasing the usual erosion rate. This direct shearing and corrosion is evident from the relatively smoothed banks remaining after the flood with little undercutting and no slumped material at the base. Often overhangs are left, bound by roots in the upper vegetation layer (Hooke, 1979). The much finer composition of the lower unit on the terrace edge will only exacerbate this effect, flowing water across this face will very quickly scour and undercut the terrace. The nature of this mechanism could explain the supposed periodic erosion of the riverbank.

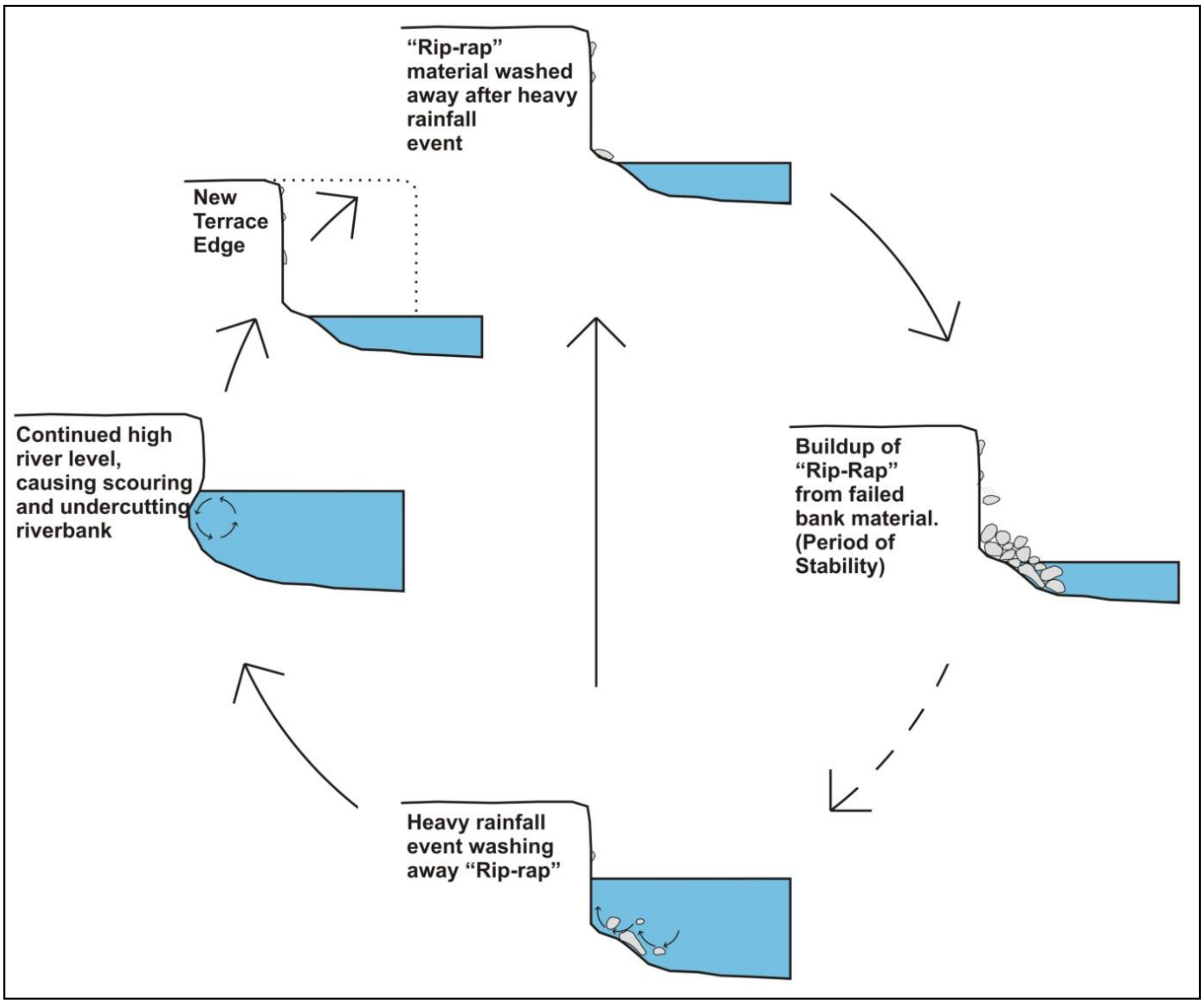


Figure 3.14 Simplified Erosion Mechanism. With a build up of enough large boulders this system could stay in a period of stability for a long period of time. Whereas when it is washed away, prolonged high river levels can cause a large amount of erosion very quickly.

3.3.5 Future Riverbank Migration

To assess how far into the fan the river may migrate across the terrace surface two river meanders were traced (Figure 3.15) and superimposed over the terrace to provide possible future pathways for the river (Figure 3.16). The current erosion rate of 35 m/yr was applied to these curves to estimate a worst case scenario timeframe it may take for the river to migrate. Curves used were a current meander directly downstream and one from the 1717 AD terrace directly upstream of the presently eroding bend.

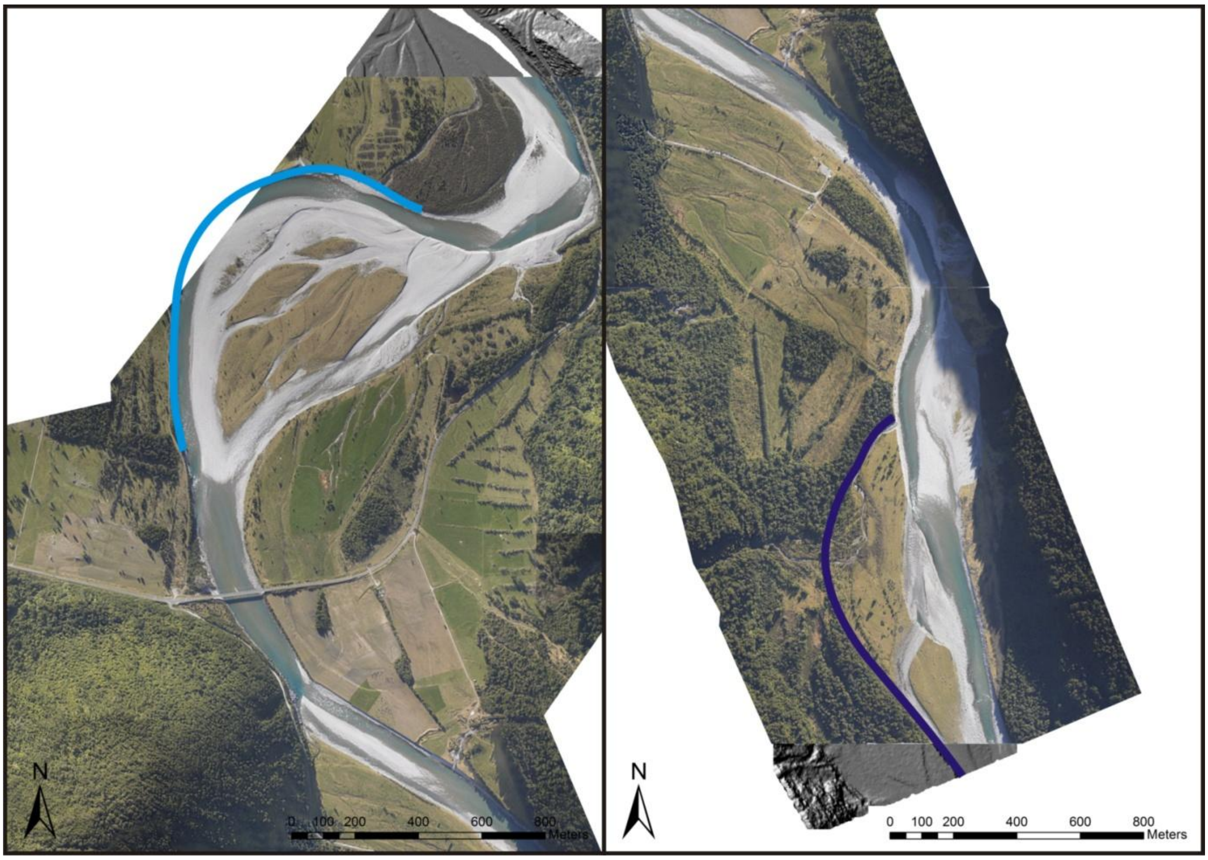


Figure 3.15 Selected curves for river migration prediction. Left: Downstream of Investigation area. Right: Directly upstream of investigation area. These curves were chosen to attempt to extrapolate the developing curve to the south of the investigation area.

It should be noted that the river curve will evolve and erosion rates will vary over time, there is no way to accurately predict where and how fast the river will migrate over such a long time period. However, here we present a possible scenario if the current high incision rates were to persist.

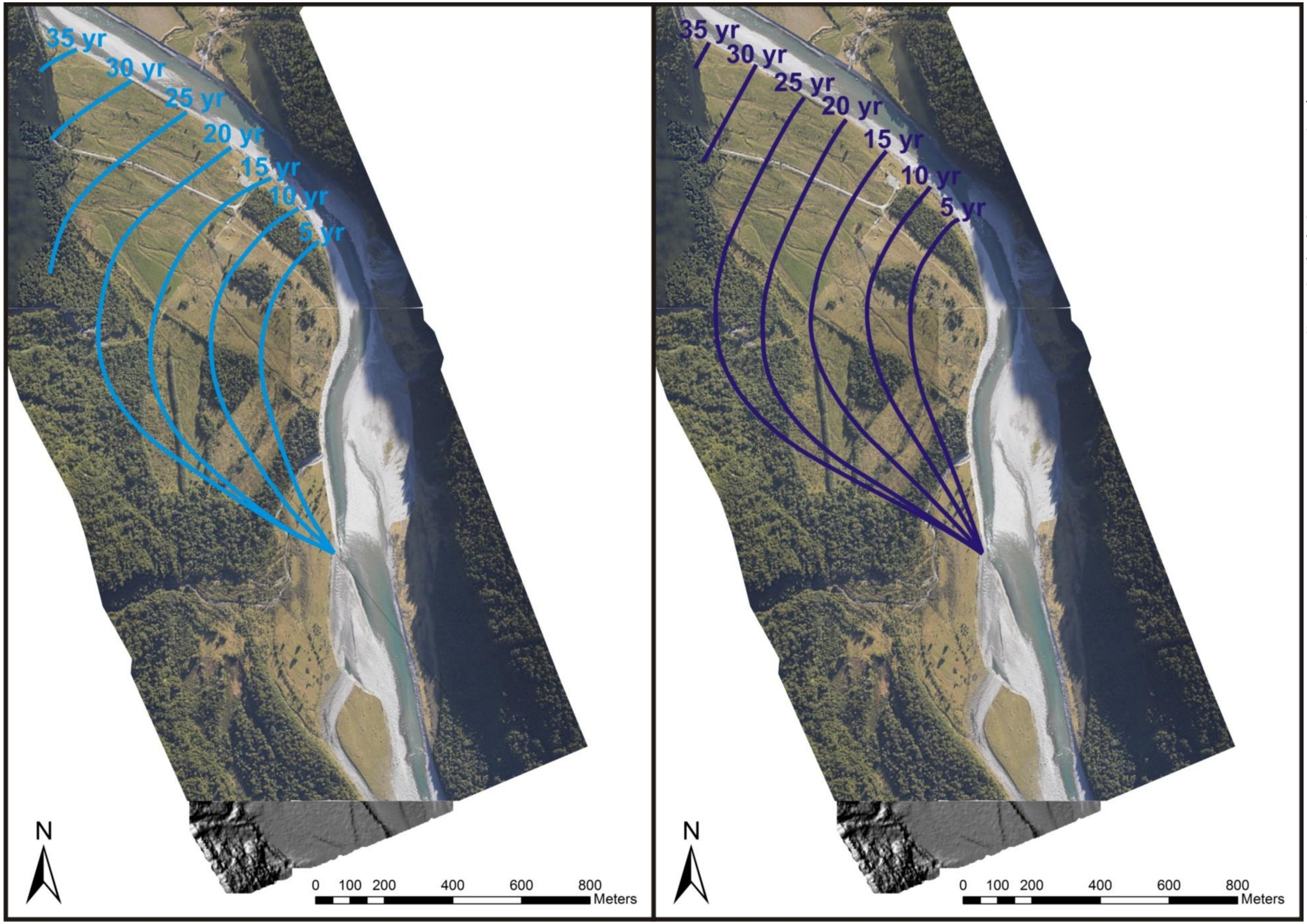


Figure 3.16 Possible future paths of river migration with time estimates assuming a persistent 35 m/yr erosion rate. Due to the confined area within the valley walls, both curves ended up projecting very similar results.

Both of the selected curves show reasonably similar results, suggesting if current incision rates persist it is possible for the entire fan to be eroded away in the next 35 years. We discuss the implications this has for drill rig placement in Chapter Four. As both curves displayed similar results we only use one of them in the summary hazard map at the end of the chapter.

3.4 Landslides and Debris Flows

The steep walls of the Whataroa river valley have been shaped by previous glaciations, the wet climate promoting thick vegetation growth on the steep valley walls create an unstable environment, where the build up of organic matter and the progressive loosening of the bedrock by tree roots will eventually give way. The major triggers for a landslide event are either, prolonged heavy rainfall causing substantial runoff and heightened water tables, or a co-seismic shaking event. Keefer (1984) states the maximum area likely to be affected by landslides in a seismic event ranges from 0km^2 at Magnitude 4 to 500 000km^2 at Magnitude 9.2. The estimated magnitude of an Alpine Fault rupture is ~M8 ±0.25 (DTEC Consulting LTD, 2002), and the fault's surface expression is ~1.5km north of the drill site. Other possible causes include changes in land management or vegetation cover, slope undercutting and increased loads on slopes. Of the recorded West Coast landslides, 224 were triggered by rainfall, 9 to earthquakes, and 14 are classed as other or unknown (DTEC Consulting LTD, 2002).

The areas where a landslide or debris flow could occur and affect the drill site have been split into four sections.

- The West side of the valley.
- The East side of the valley.
- Upstream of the investigation area.
- Downstream of the investigation area.

3.4.1 The West Side

Debris flows on the West side of the valley pose the greatest threat to directly affect drilling operations. There are a number of historical and active debris flows along the western valley wall. Detecting events that have recently occurred (~100 years) is relatively easy. Large areas of younger vegetation that have been cleared out stand out on the valley wall, these often have an active stream running through it. These are mapped on the Summary Hazard Map at the end of the chapter.

The most recent debris flow occurred during the summer of either 2009 or 2010 (Friend, 2010, pers comms.). It ran out ~80m from the valley wall and destroyed a recently installed cattle fence. The flow is composed of angular to sub angular rocks and boulders up to 4 m wide as well as sands, trees and branches. The recent event was likely reworking of a previous debris flow deposit by heavy rainfall, as the deposit is visible in the 2002 aerial photo and there is no sign of layering of different events. Over the past year it has remained inactive, the photos below, A, taken in June 2010, and B, in September 2011, are nearly identical.

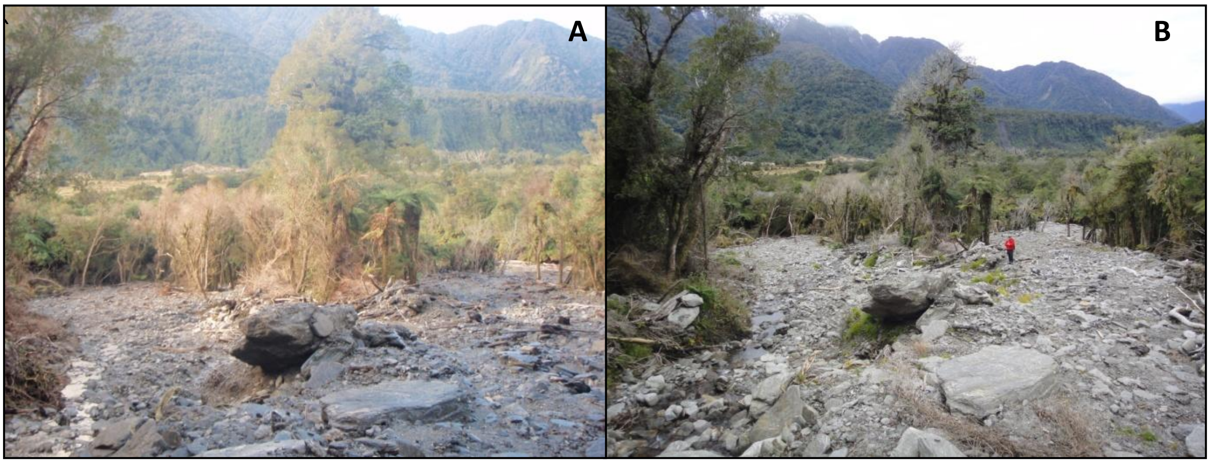


Figure 3.17 Recent landslide in the Whataroa A. June 2010, B. September 2011. Both photos are nearly identical suggesting little activity over the previous year.

Identifying the extent of older events has been difficult, as the thick vegetation disguises out many geomorphic features. The LiDAR data was very useful here, at the bottom of the valley wall channels, there are discrete mounds of debris, the largest one extends about 90 m out onto the terrace surface. If a debris flow was to occur with sufficient run out it could affect a drilling operation by directly impacting the rig and run the risk of causing injury or loss of life. It could also affect operations indirectly by creating a dam or changing water pathways. An example is a large slip, estimated to have occurred early last century, near the old State Highway road. It is easily spotted and aerial photos from 1948 show it creating a dam causing the water pathways on the terrace to back up (Figure 3.18).

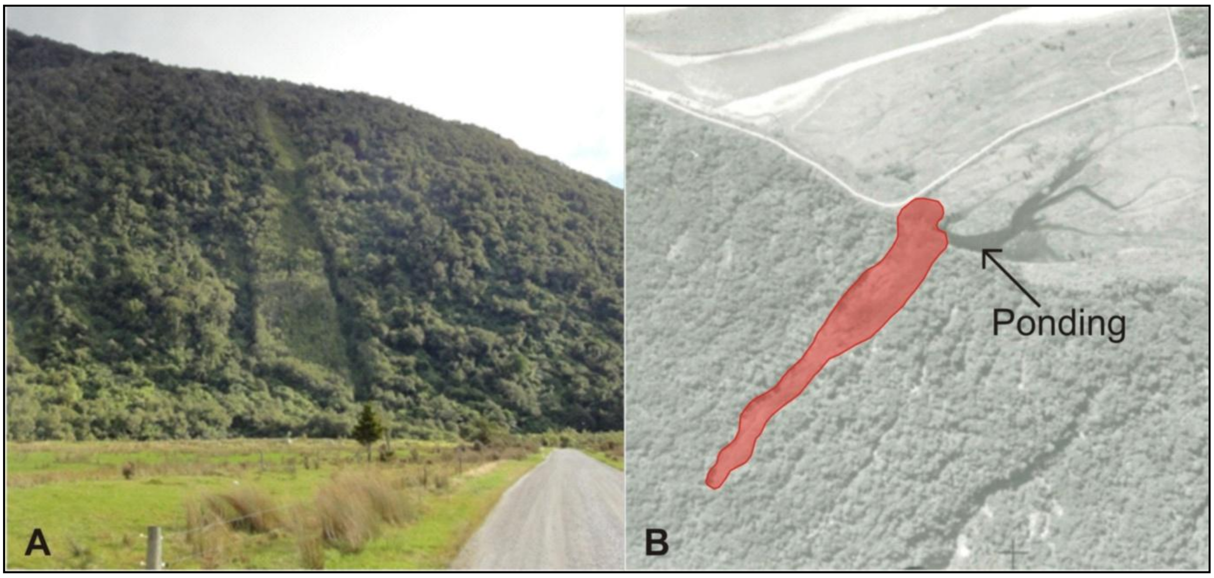


Figure 3.18: A. Present view, distinct change in vegetation outlining the silp. B. 1948 aerial photo illustrating the damming effect caused by the slip.

To estimate the run out of these events and outline a “risk zone”, a profile down each debris flow was taken from the LiDAR (Figure 3.19). Three zones were identified in each profile, (1) the hill slope, (2) the area of deposition of the debris flow, and (3) an area past the deposition zone where heavy rain fall has reworked the finer material and spread it out further onto the fan. In all cases, the deposit extends a maximum of ~90 m onto the fan surface and the reworked material has been moved a maximum of 50 m. This suggests that these flows lose momentum very quickly upon hitting a flat surface and will not have momentum to run out onto the terrace very far. A debris flow will continue to move on a slope less than 10-15 degrees, however rarely on a slope of 5 degrees or less (Hyndman & Hyndman, 2005). Therefore, the edge of this reworked area is estimated to be the extent of where the debris flows affect the terraces. This is used for the basis of the debris flow “risk zone” on the summary hazard map at the end of the chapter.

If a debris flow was to occur again in the same location, any existing deposit could provide the necessary slope for it to run out further, therefore an extra 50 m buffer on this is suggested for the debris flow “risk zone”. A possible remediation solution for this hazard is stop banks to protect the drill site, or berms to attempt to divert any flows away.

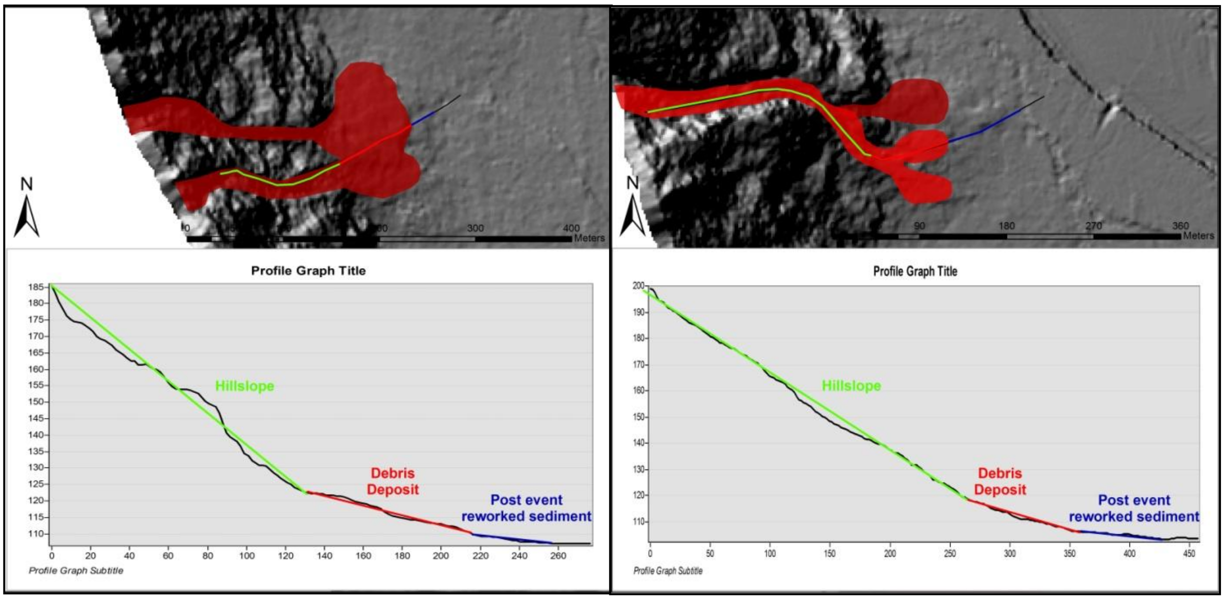


Figure 3.19 Segmented profiles of selected debris flows on the Whataroa Valley wall. There are two distinct surface angles where the deposit sits. The first (red) is interpreted as the original deposit, after hitting the flat terrace surface these do not run out very far. The second (blue) is interpreted as reworking and spreading of the deposit by heavy runoff.

The stream that borders the south of the investigation site also shows signs of major debris flow events. The effects of these events are well out of the range of any possible drilling locations.

3.4.2 The East Side

The ~100m high gravel cliffs on the East side of the valley (Figure 3.10), do not pose a direct threat to the site, however if they were to catastrophically fail they could cause the Whataroa river to avulse, thereby increasing erosion rates at the cutbank towards the drill site, or cause avulsion onto the work area. There is no evidence of this happening in the past.

3.4.3 Upstream

The third scenario considered, is a major landslide further up the Whataroa Valley. This can have long term effects such as gradual river aggradation causing avulsion, and migration of the river channel, likely causing new areas of erosion and scour in many locations downstream of the slip. Or, it could completely block the river, creating a landslide dam, if the dam was to fail it would flow down the valley as a major debris flow. Short of creating very large berms and stop banks, the only way to avoid this hazard is to place the drill rig on the highest terrace away from the river and to monitor the catchment for any large scale slips upstream from the drill site.

Here we calculate the amount co-seismic river aggradation it would take to put the 1717 terrace “within reach” of a 50 year flood, which has a discharge of 4918 m^3/s.

Assuming static width of the current river channel, a range of different aggradation amounts were added to the cross sectional area to see if the discharge would overtop the surface. This showed that it would take ~5 m of aggradation (an addition of around 1500 m^2 to the river cross section) to make the 1717 fan prone to a 50 year flood. The 1717 aggradation aggraded 5 – 8 m in the main valley (McSaveney, 2002), and this is expected to be a small aggradation event. With the long period of time since the last major earthquake on the Alpine Fault and the amount of sediment expected to be injected into the system in the next event, this scenario is entirely possible.

3.4.4 Downstream

The last area that could affect the site is downstream of the terraces. Large Deep seated bedrock landslides pose a threat along the faulted range front on the West Coast. Two examples are the Wanganui-Wilberg Rock Avalanche at the valley mouth of the Wanganui River (Chevalier, 2008) and the Round Top debris avalanche between the Toaroha and Hokitika Rivers (Wright, 1998). These landslides can affect areas on a square kilometres scale. If one of these occurred at Whataroa it could (1) directly impact the drilling operation or (2) block the Whataroa River causing it to back up and inundate the terraces. Similar to what is illustrated in Figure 3.18 B, however on a larger scale.

3.5 Earthquake Hazard

Due to the sites location on an active boundary structure, the Alpine fault, between the Australian and Pacific plates, earthquakes are a major and inevitable hazard. Although there has not been any movement on the Alpine Fault recently, the previous event dated at 1717 AD which had an estimated dextral movement of 8m, and a rupture length of 375km (Wells et al., 1999), possibly 450km (DTEC Consulting LTD, 2002). Effects of a major M8 earthquake while drilling include ground shaking and rupture, earthquake induced landslides and associated hazards (previously discussed), liquefaction, and disruption to infrastructure. The last three Alpine Fault events have all ruptured at Whataroa (Figure 1.1) therefore it is highly likely that the next event will also rupture there.

Using the Hanks & Bakun, (2002) source-scaling model for large continental earthquakes with rupture area (A) > 537 km^2,

M = 4/3 LOG A + 3.07 (+/- 0.04),

And using approximated rupture lengths from Figure 1.1, we derive a range of M estimates of 7.5 to 8.1 (7.8 ± 3) for the three most recent Alpine Fault earthquakes, using a rupture width of 10 km. Increasing the down dip rupture width would increase the magnitude estimates.

Table 3.4 Earthquake rupture lengths approximated from Figure 1.1 and other parameters used for Hanks and Bakun (2002) source-scaling model for large continental earthquakes to derive magnitude estimates for the three most recent Alpine Fault rupture events

Earthquake (Date)	Width (km)	Fault length (km)	Rupture area (m^2)	Magnitude (M)
1430	10	280	2800	7.666211
1430	10	600	6000	8.107535
1620	10	200	2000	7.471373
1620	10	330	3300	7.761352
1717	10	370	3700	7.827602
1717	10	520	5200	8.024671

3.5.1 Likely location of fault ruptures

It is important to identify the size of a fault, and its location relative to the investigation area in order to (1) estimate the amount of ground shaking that will occur at the site in an event, and (2) avoid areas that are likely to experience surface rupture. Here we investigate the location of potential seismic hazards near the site.

3.5.2 South Westland Fault

The South Westland Fault zone is a proposed distinct zone of shear faulting in Tertiary rocks that trend parallel to the Alpine Fault and is mapped onshore approximately 10 km from the site at Whataroa (Cox & Barrell, 2007) (Figure 3.20). It is characterised by closely spaced faults, separating steeply dipping slices of

Figure 3.20 Approximate location of the South Westland Fault and Shear Zone. Modified from Benn (1992) with data from Cox & Barrell (2007) and Rattenbury, Jongens, & Cox (2010)

Tertiary rocks (Benn, 1992). Quaternary deposits have buried large areas of this fault zone and it is proposed that more research required to establish the exact nature and history of faulting.

3.5.3 The Alpine Fault

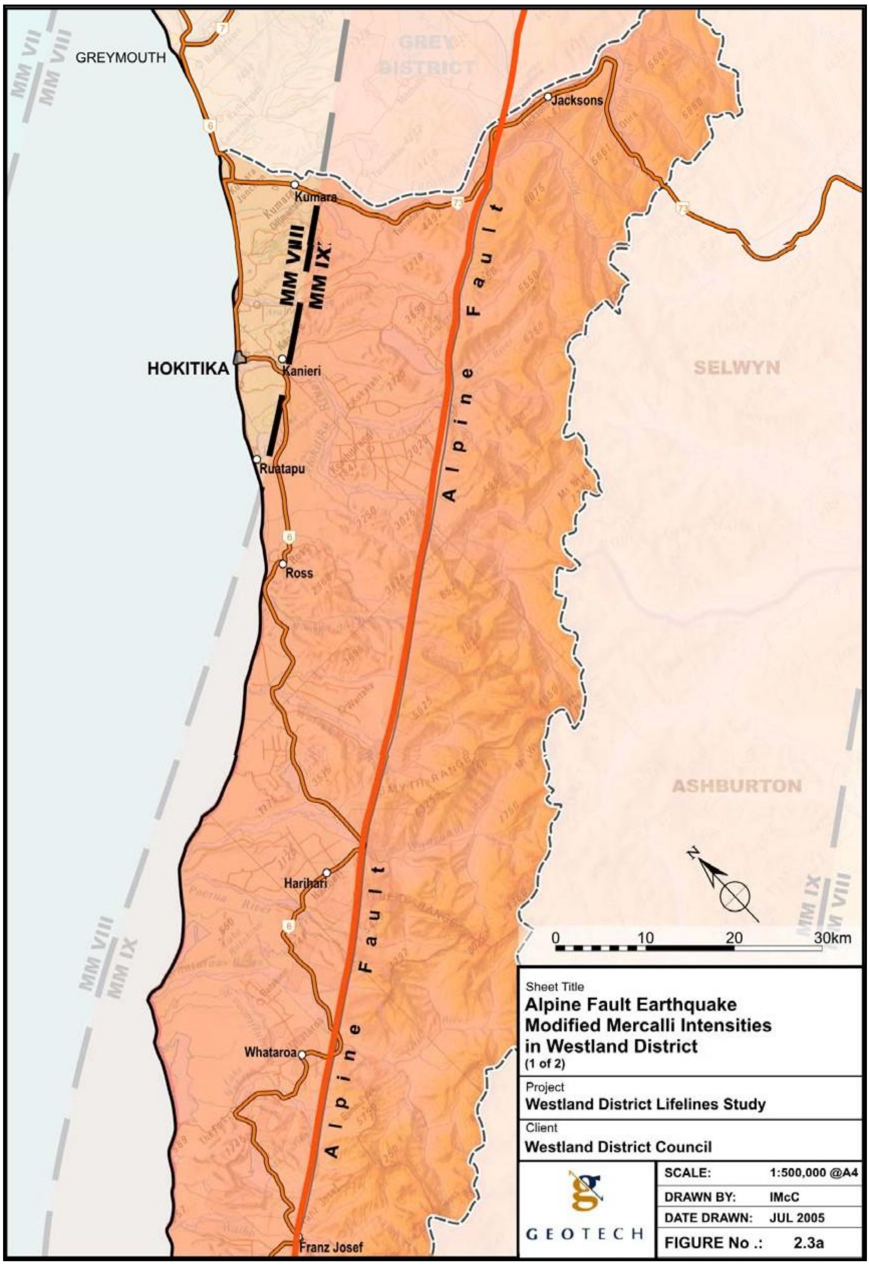


Figure 3.21 The location of the Alpine Fault in the regional setting and Modified Mercalli Intensities in the Westland District (Westland District Council, 2006). This is the major seismic threat in the area. The Alpine faults location in relation to the investigation area can be found on the series of maps in Appendix B

3.5.4 Likely PGA's

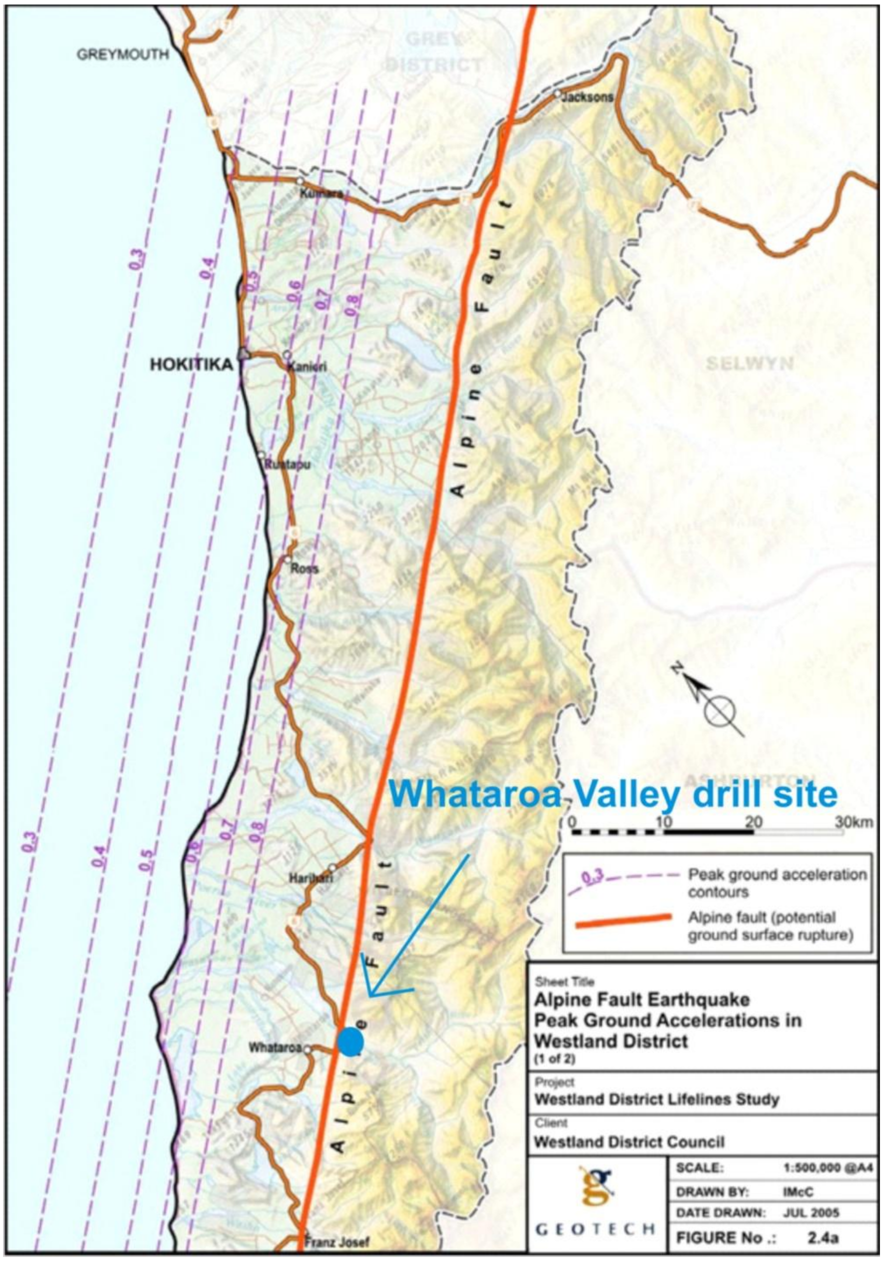


Figure 3.22 Alpine Fault earthquake peak ground accelerations for deep soils in Westland District (Westland District Council, 2006). The Whataroa drill site is illustrated here for reference to its location over the fault line.

Peak ground acceleration (PGA) is the maximum acceleration that occurs at the ground surface during an earthquake, and is normally expressed as a factor of the acceleration due to gravity. Classing of the soils in the previous chapter to a class D soil puts the site in the lower end of ground shaking Zone 1 of the Westland District Council Lifelines Study. Figure 3.22 to the left is the corresponding PGA map for Zone 1 soils, it illustrates that the site at Whataroa will receive a minimum of 0.8g PGA during an Alpine Fault event. Due to the sites proximity to the fault trace (~1 km) and the nature of the soils, it is likely it will be much higher.

3.5.5 Probability Calculations

A number of papers present a range of probabilities for the next Alpine Fault earthquake, each using different methods of calculation and measurements.

Table 3.5 Probability Estimates for the Next Earthquake on the Central Section of the Alpine Fault (Yetton, Wells, & Traylen, 1998).

Years from 2002	Probability of an Earthquake Event (%)	
	Average	Range
5	10	6-14
15	27	12-26
20	35	20-45
30	45	30-60
40	55	40-70
50	65	50-75
70	75	60-90
100	85	75-95

Table 3.6 Estimated probability of rupture of the Alpine Fault central section starting in the year 2002 AD, using four different recurrence-time models, and taking into account uncertainties in data and parameter values. Taken from (Rhoades & Van Dissen, 2003).

	Time interval			
Model	**1 yr**	**20yr**	**50yr**	**100yr**
Exponential	0.0051	0.097	0.22	0.39
Lognormal	0.01	0.18	0.38	0.6
Weibull	0.012	0.21	0.44	0.68
Inverse Gaussian	0.0073	0.14	0.3	0.5

The Yetton et al. Paper gives annual probabilities that range from 0.85 – 2%. Whereas the Rhoades & Van Dissen paper is more conservative producing probabilities between 0.5 – 1.2 %. All of these values are several orders of magnitude greater than the probabilities calculated for flooding in Section 3.2. Therefore we conclude the chance of an Alpine Fault rupture within this century poses a much greater risk to the site than flooding.

3.5.6 Alpine Fault MASW Line Imaging Results

To address the location of the Alpine fault near the site, we attempted to image the Fault immediately downstream of the state highway bridge where the fault is projected to cross the 1717 AD terrace. There is no surface expression because the terrace is likely to be post seismic and any trace of a surface rupture will have been covered.

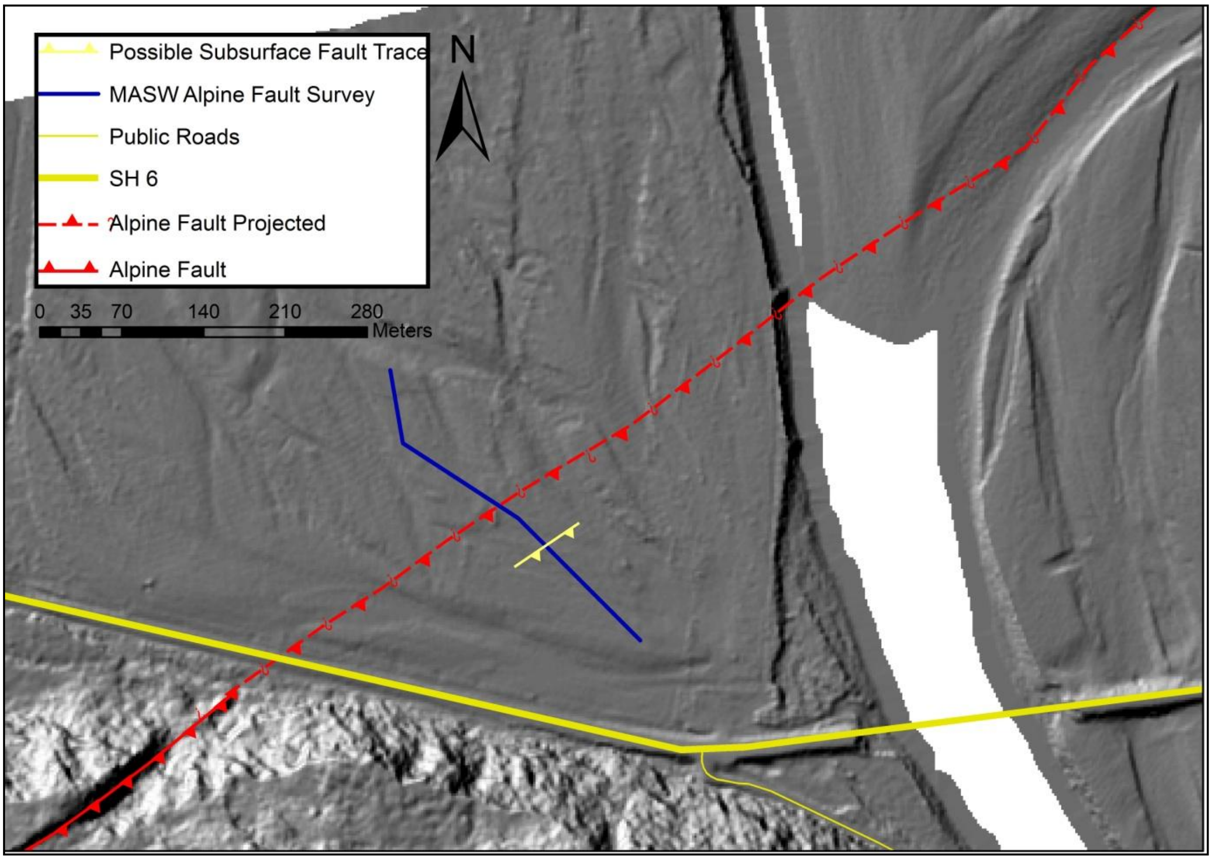


Figure 3.23 Alpine Fault projections and location of the Alpine Fault MASW survey.

The profile mostly showed similar s-wave velocities to the previous MASW surveys, suggesting a composition of similar gravels. There was a small zone to the south of the profile returning s-wave velocities up to 800 m/s, indicating the possibility of bedrock. In the processing there was a lot of back scatter around the 200 m mark. This could be interpreted as a fault scarp and fractures or some kind of buried vertical face. This back scatter could also have created anomalies in the profile.

Here we propose two interpretations for the resulting MASW profile. The first is a possible location of the Alpine Fault in the subsurface of the Whataroa alluvial fan (Figure 3.23), the second is interpreted as old buried river channels (Figure 3.25).

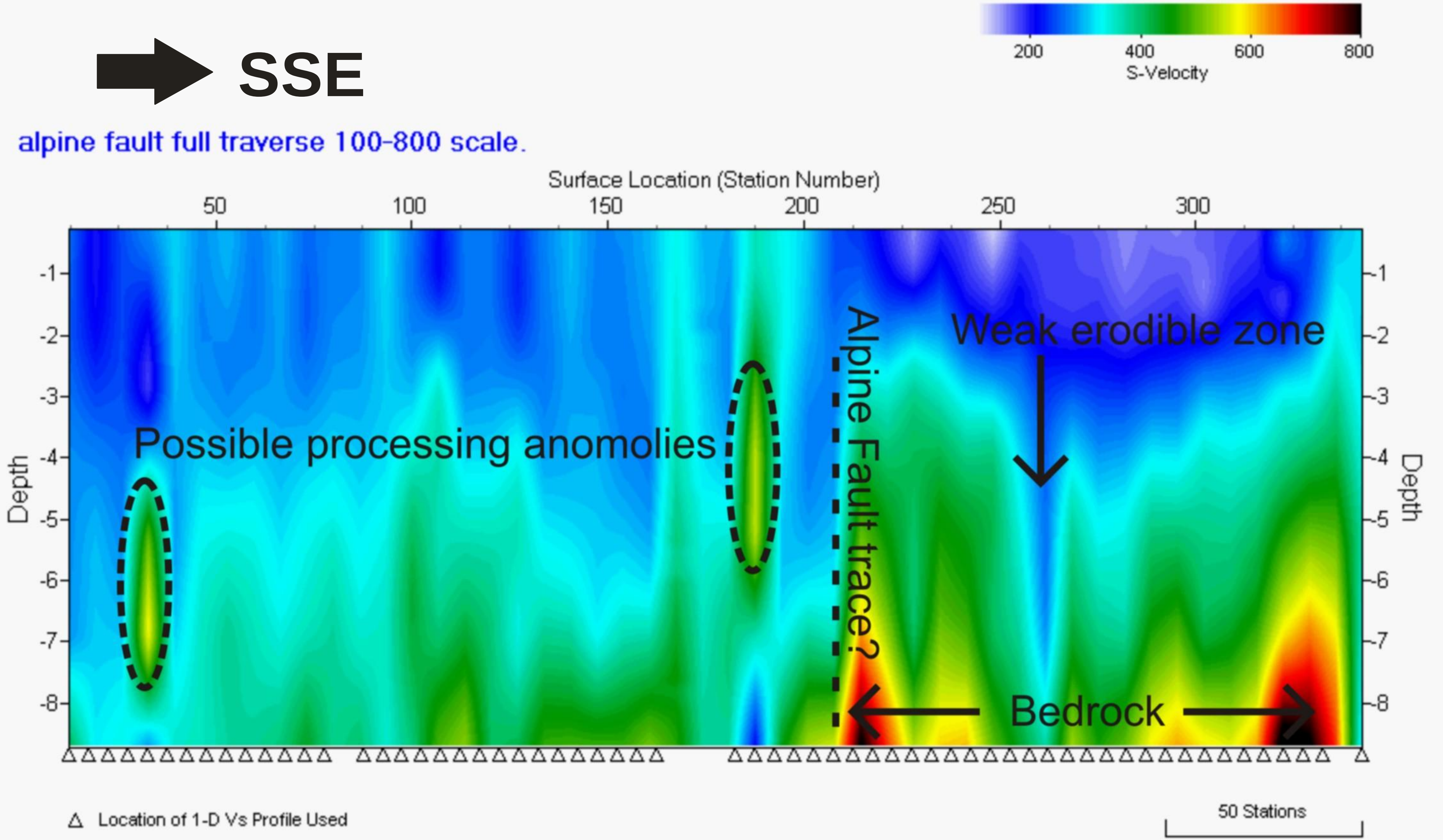


Figure 3.24 Alpine Fault MASW survey interpretation showing a possible Alpine Fault trace location. The weak erodible zone could be composed of extremely metamorphosed rock, similar to that seen at Gaunt Creek

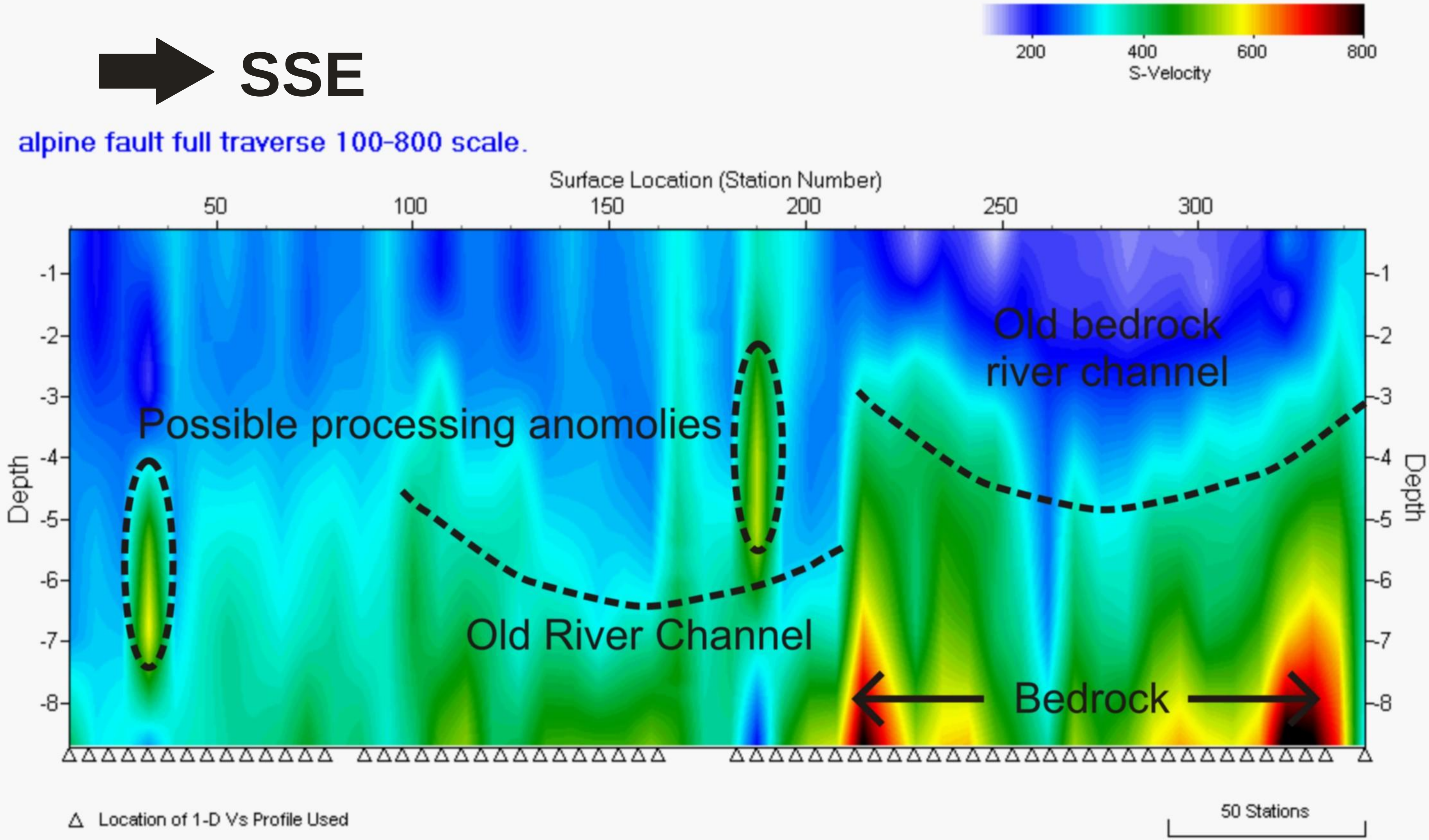


Figure 3.25 Alpine Fault MASW survey interpretation based on old river channels.

3.5.7 Whataroa Terrace Trench

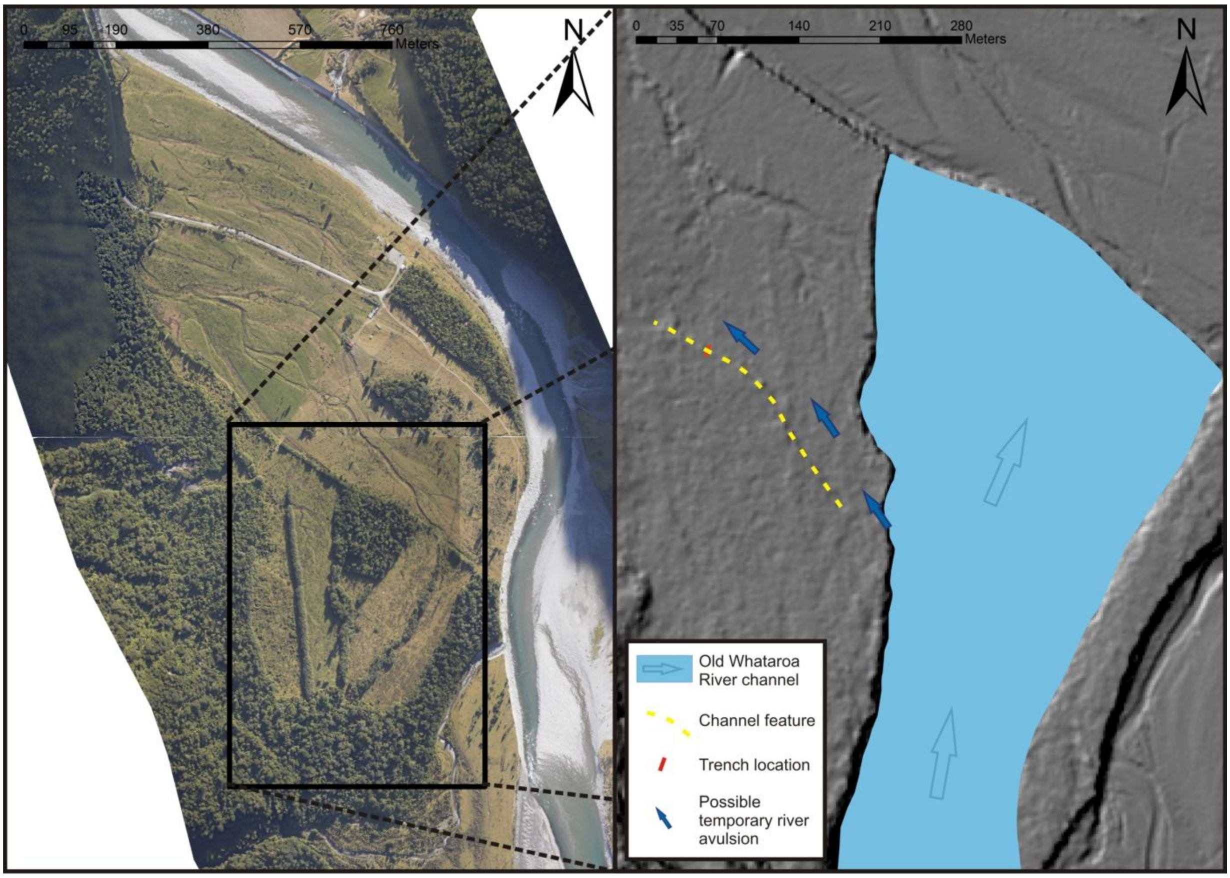


Figure 3.26 Possible formation of the trenched channel feature.

At ~120 m down the WHAT0 GPR profile, there is a steep feature that has dipping or offset reflectors and a lack of signal beneath it. This could be interpreted as a fault, or as the edge of an incised and in filled channel. The feature also matched up perfectly with a sharp ~1.5m change in topography (Figure 3.26) that trends NW-SE for ~250m.

To identify the nature of this feature, a small test trench was dug across it. This revealed it to be an old incised and in filled channel. There were no offset beds, and no signs of a fault plain (disturbed gravels, striations etc.). This could possibly have been carved out by one of the streams running off the west side of the valley, or during a temporary river channel avulsion from a historical Whataroa River flow path (illustrated in Figure 3.26). The results of the trench are correlated with the What0 GPR profile in Figure 3.27.

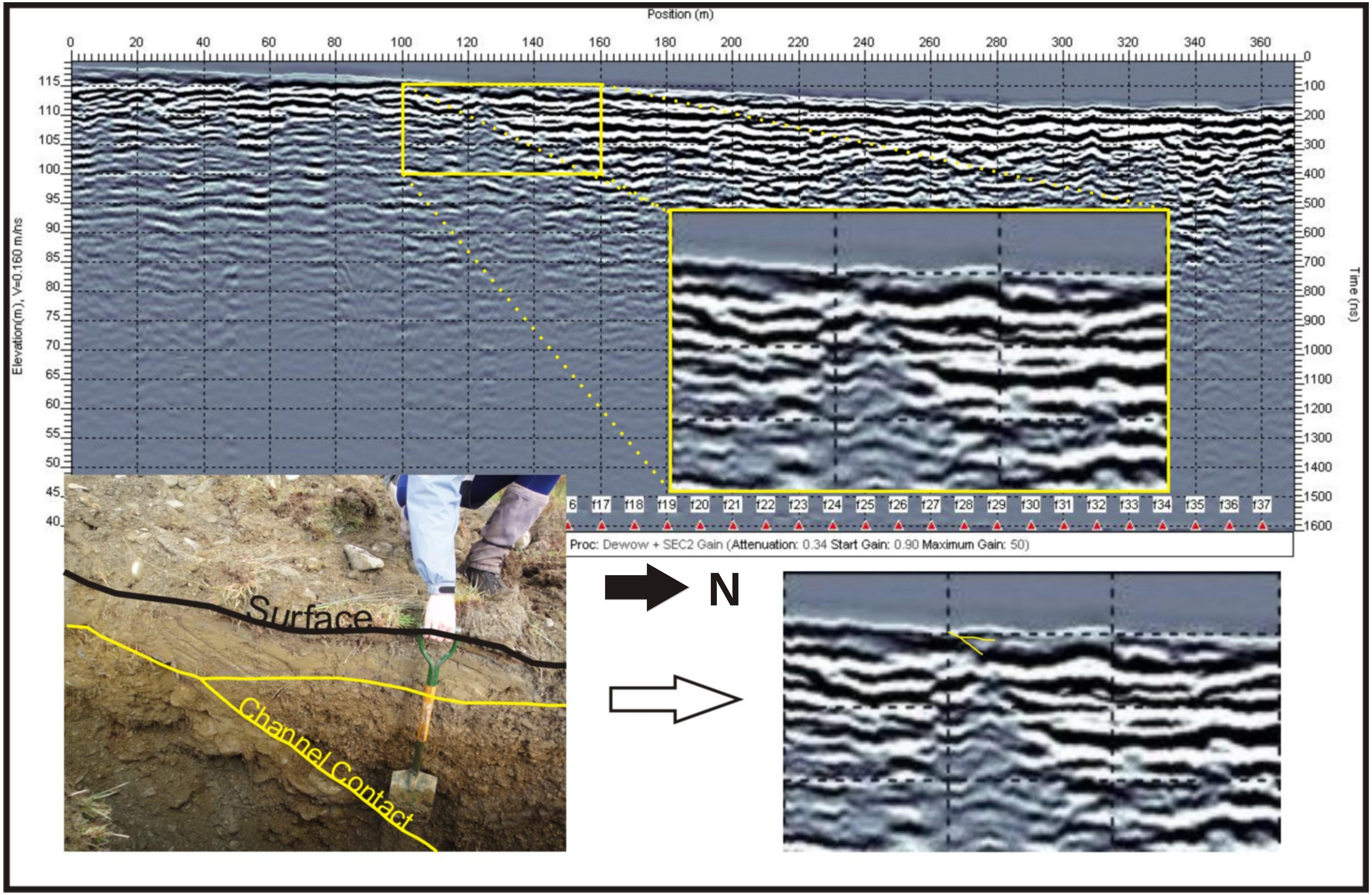


Figure 3.27 Trench compared with the What0 GPR profile line. The on lapping contacts in the GPR profile correspond well with what was found in the trench; a finer gravel in an old stream channel on lapping onto a coarser gravel.

3.5.8 Liquefaction & Subsidence

Liquefaction is most likely to occur in saturated, relatively uniform loose fine sands and coarse silts close to the surface (<15m) (Seed & Idriss, 1982). The materials present at the site are predominantly very coarse well drained gravels suggesting they are not prone to liquefaction. Where there are silts and fine sands present, it is a thin veneer on the surface. However, at very close distances to the shaking source, some liquefaction is possible in more gravel rich sediments not normally considered liquefiable. Taking this into account, zones could possibly be classed as liquefiable where the gravel matrix is particularly sandy, and where there are sand lenses and bars to the north of the terraces.

Because of the loose nature of the gravels, although they may not be prone to liquefaction, it is likely that they will undergo a small amount of settlement during an earthquake. Due to the sites proximity to the fault, co-seismic ground damage is possible during a major shaking event.

3.6 Summary Hazard Map

The relevant hazards discussed in this chapter are compiled onto one map. The flooding and inundation hazard has been plotted on, but is deemed a low risk related to the effects of the high probability of an Alpine Fault earthquake. Localised inundation has been included. Debris flows and the “risk zone” and “buffer zone" was included on the map. Channel migration rates have been extrapolated to estimate possible future stream channel locations. The earthquake hazard and estimated PGA values are not displayed, the PGA is assumed at +0.8 for the whole map.

This map with respect to placing a drill rig is discussed in Chapter Four.

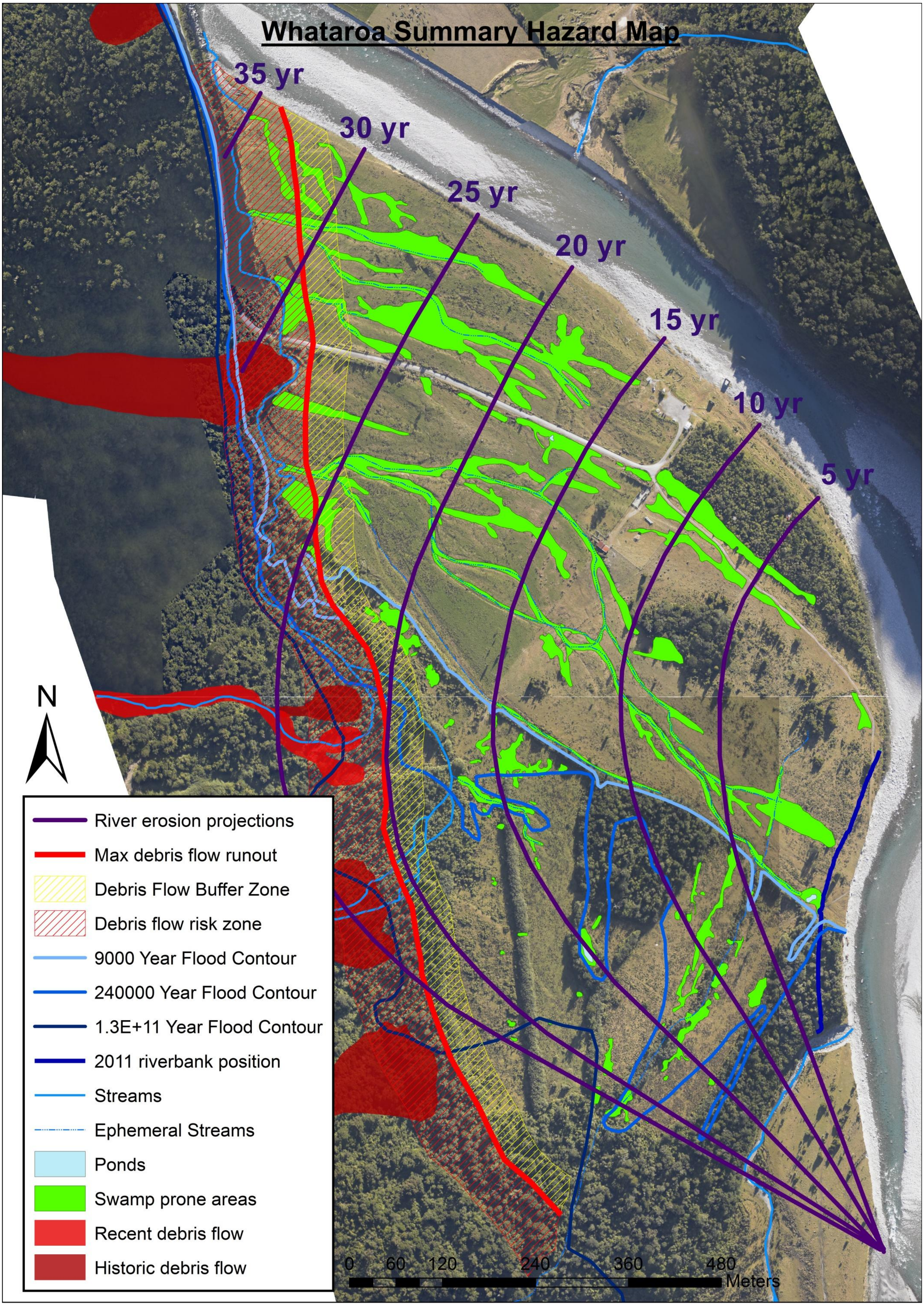


Figure 3.28 Summary of the potential hazards that could affect a drilling operation in the Whataroa Valley. These are discussed with respect to sighting a drill rig in Chapter Four.

4 Proposed DFDP2 Site Locations

One of the major complications encountered with this project was the scientific placing of the drill site. To date there is much debate over the angle of dip of the Alpine Fault at depth. With this uncertainty it is extremely difficult to pin point a single site for investigation. Common estimations of the dip are ~40-50° (Davey, et al., 1998) (Liu & Bird, 2002) (Walcott, 1998), therefore a target of 1.5km depth would place the drill site ~1.5km away from the surface expression of the fault. However, a 15° change in dip would require movement of the drill site up to 1.1 km closer or further away from the surface trace to intersect the fault at the same depth as illustrated in Figure 4.1. Therefore there is a very wide area to investigate for possible drill rig locations. Increasing the uncertainty of the drill rig location, the target depth of 1.5 km is subject to change.

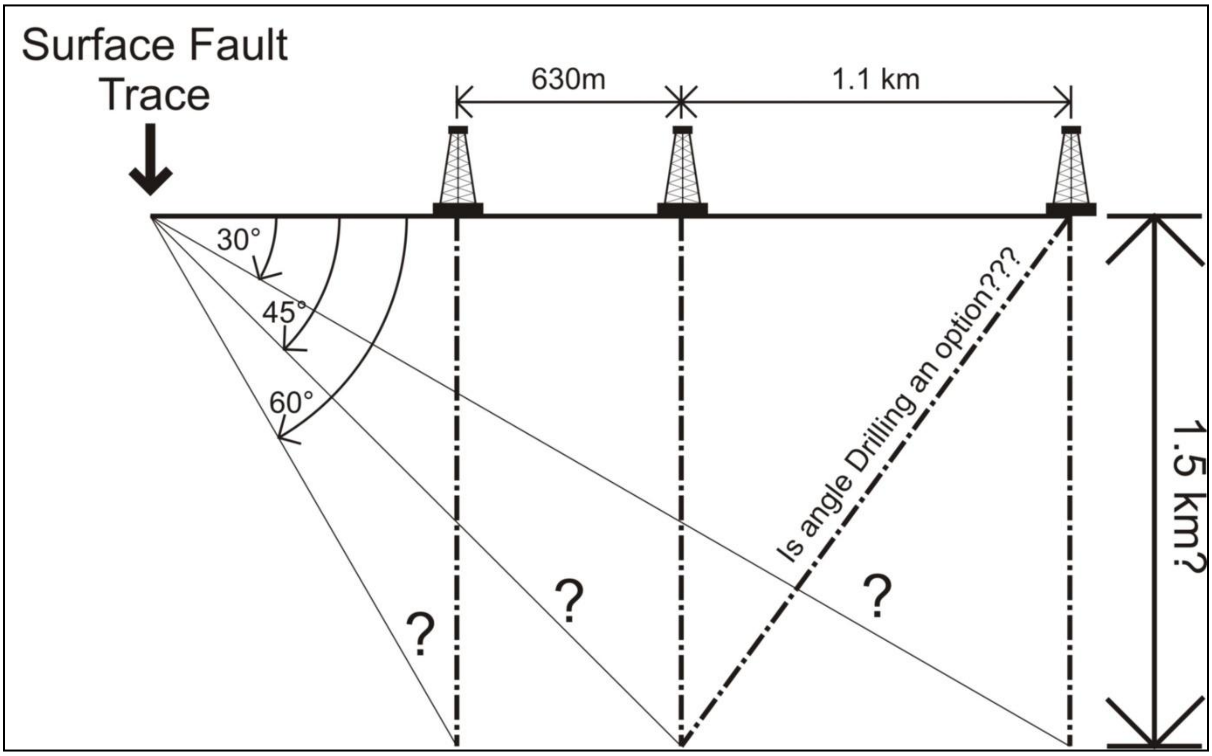


Figure 4.1 Effect of varying fault dip estimations highlighting the large variability of surface location for a drill site with slight uncertainties of the fault dip.

This chapter combines investigations in the previous two chapters, and ties them to a range of fault dip angles to identify a number of favourable locations to place a drill site.

4.1 Effect of Different Fault Dips and Geometries

Using basic trigonometry, a number of distances from the Alpine Fault surface expression for a 1.5 km drill hole were calculated using different fault dips Table 4.1. Also the commonly accepted scenario of the Alpine Fault dipping at 45° was chosen and distances from the surface trace were calculated to illustrate the effect of varying borehole target depths Table 4.2.

Table 4.1 Fault dips and corresponding distances from the surface expression for a 1.5 km deep drill hole.

Fault Dip (°)	Distance from surface expression (km)
20	4.12
25	3.22
30	2.60
35	2.14
40	1.79
45	1.50
50	1.26
55	1.05
60	0.87
65	0.70
70	0.55

Table 4.2 Varying borehole target depths and corresponding distances from the surface expression based on a 45° dip of the Alpine Fault.

Borehole target depth (km)	Distance from surface expression (km)
0.5	0.5
0.6	0.6
0.7	0.7
0.8	0.8
0.9	0.9
1.0	1.0
1.1	1.1
1.2	1.2
1.3	1.3
1.4	1.4
1.5	1.5
1.6	1.6
1.7	1.7
1.8	1.8
1.9	1.9
2.0	2.0

A series of lines running parallel with the Alpine Fault that correspond to each possible 5° dip increment (Figure 4.2), and structure contours for a fault dipping at 45° for varying target depths to intersect the fault (Figure 4.3) were plotted over top the Whataroa Terraces to identify possible drilling locations.

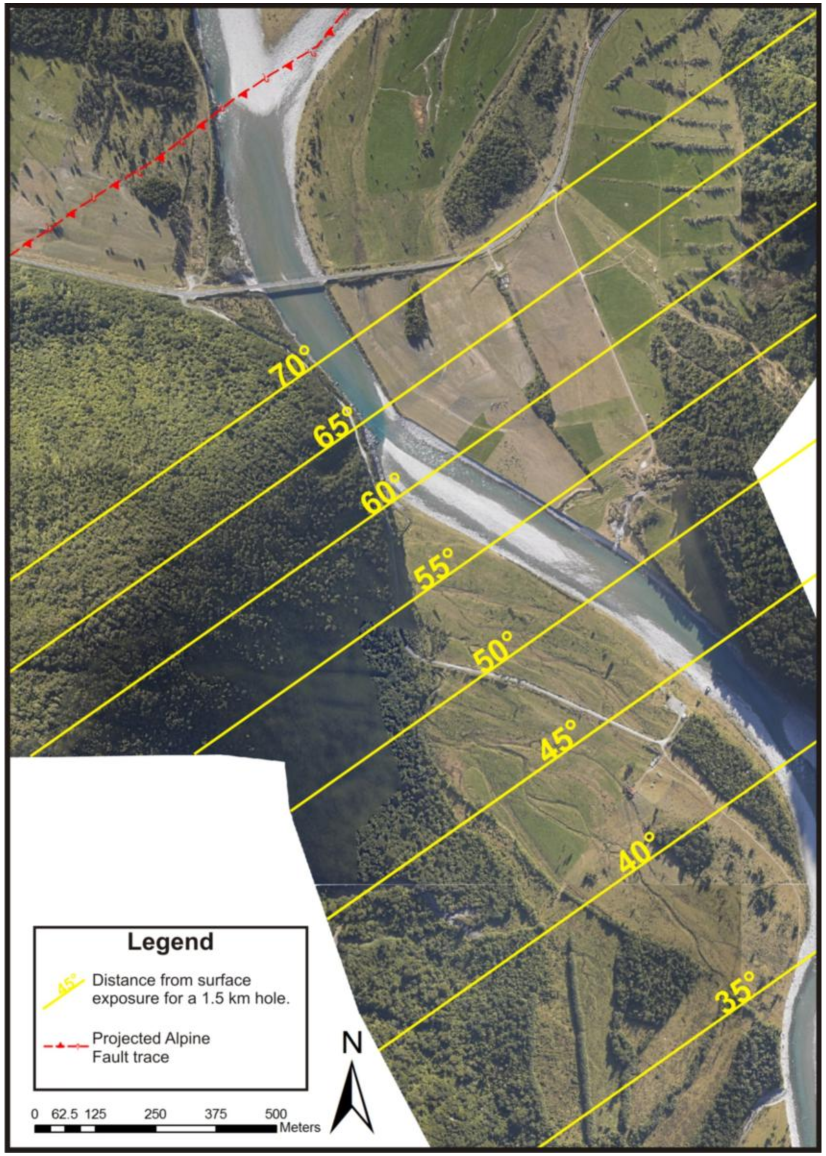


Figure 4.2 Distances from the Alpine surface expression for a 1.5 km drill hole with varying fault dips.

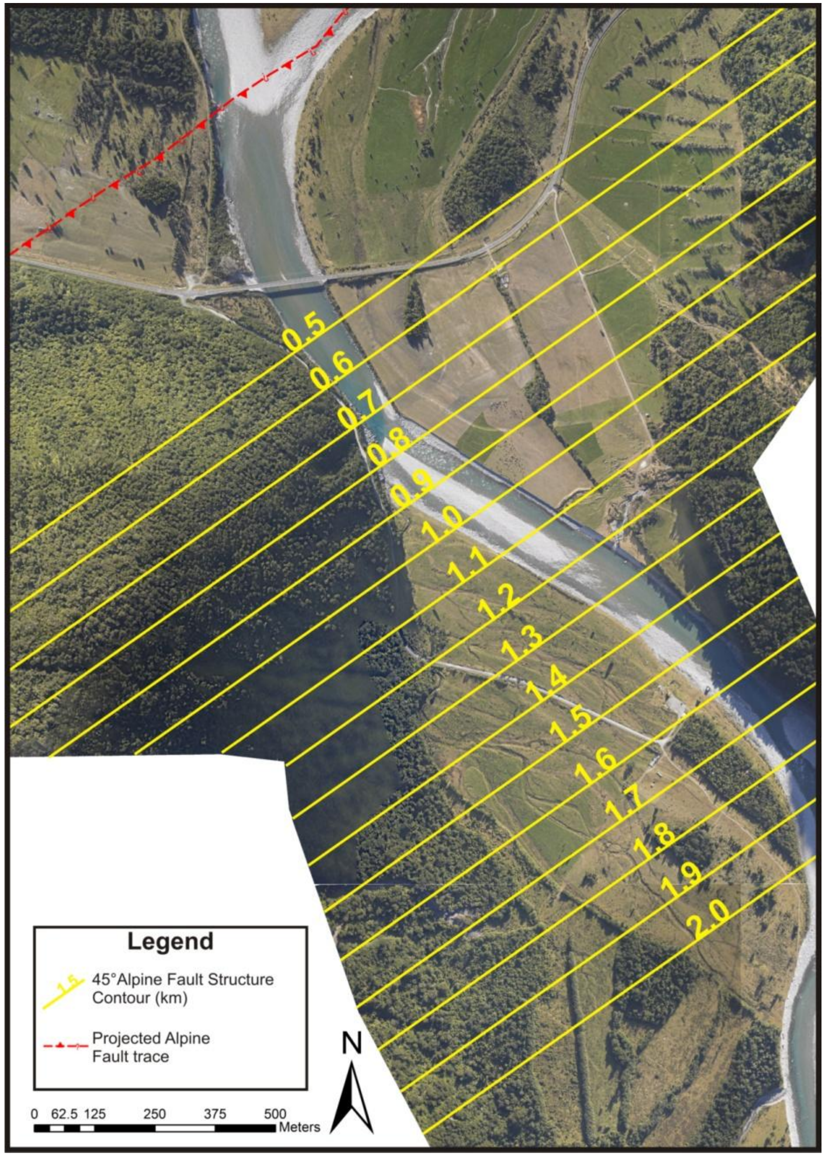


Figure 4.3 Distances from the Alpine surface expression for a fixed dip of 45° with varying bore hole target depths.

4.1 Discussion and Proposed Drill Site locations

As stated at the beginning of this thesis, the suitability of a site for stationing a major drilling operation depends upon practical issues such as the engineering geological characteristics of the proposed site, possible geohazards, and drilling logistics. Here the results of new engineering geological, geophysical, and geomorphic investigations of the Whataroa Valley are summarised and discussed to outline a framework that should be used for proposed future operations, and the criteria used for suggesting the drilling locations on Figure 4.4 is stated.

MASW and basic geotechnical methods such as test pits and face logs gave insight to the shallow subsurface properties of the site. With exception to the zones of deep sand which have been interpreted as old sand bars and should be avoided, most of the fan has a reasonably competent substrate that is expected to be able to withstand a temporary drilling structure and monitoring station. With the 1620 AD and 1717 AD gravels giving an inferred bearing capacity of ~75 – 90 kPa. However, the testpits showed there is often a thin veneer of loose sand on the surface, this should be removed when constructing the drill pad to get to more stable gravels. The V_s30 values derived from the MASW profiles gave between 228 and 363 m/s classing the gravels as a soft soil in Site Class D in NZS 1170.5. Expected peak ground accelerations at the study site during an Alpine Fault earthquake are estimated at ≥0.8g.

Attempts to image bedrock depth with GPR showed bedrock is at least 25m deep. Correlation of the GPR profiles with the MASW and face logs of the freshly eroded gravel outcrops permitted assignment of s-wave velocities to each of the gravels units present and confirmation of features seen in the geophysical surveys. Therefore, geophysical investigations before a drill site is placed can provide an easy way to check the sub surface for suitability, as it can be correlated with the geophysical investigations completed in this thesis to assume a subsurface model.

Debris flows originating from the west valley wall have been identified as a hazard to drilling operations. It is possible an event could occur anywhere along the valley especially if the trigger is a large earthquake. Studies of these shows that upon hitting the flat terrace surface, they quickly lose momentum and have a run out distance of less than 100 m. These can be easily avoided by ensuring the drill site is located outside the proposed debris flow risk zone and the 50 m buffer that has been added for caution.

The Whataroa River is actively eroding the southern edge of the investigation area. The investigation showed the river bank has moved a total of 165 m since 1948. 80 m up until 2002, 50 m between 2002 and 2010, and 35 m in the past year, this occurred over a few days during early January 2011. This highlights the Whataroa Rivers apparently increasing potential for large scale channel migration over short periods of time. There is little correlation between heavy rainfall periods and increased erosion rates. Further study into this showed that the rapidly decreasing curve radius of the river meander is the likely governing factor behind this increasing erosion rate. Attempted projections of channel migration suggest that at current erosion rates it is possible that the entire set of terraces have the potential to be eroded away within ~35 years. If the project was only looking to avoid the river migration for the duration of drilling, it is safe to assume that any spot 200m away from the river will be safe for the next five years. However, if the operation is looking to place a monitoring station there for 50 years, it is hard to predict how the river will behave over such a long period of time. It is unlikely that the channel dynamics will be the same in 35 years. The river may migrate over the other side of the valley or the curve may widen, reducing its eroding power. Therefore, it is more probable that it will take longer than 35 years for the river to remove these terraces. The Whataroa Rivers erosional potential is a factor that should strongly influence where the drill rig is located. A long term operation should be located as far away from the river bank as possible.

With a 45% chance of an earthquake on the Alpine fault in the next 30 years (DTEC Consulting LTD, 2002), it is highly possible that an event will happen before the river can erode even half the terraces at the current incision rates. If this were to happen the monitoring station could be damaged due to strong shaking or, the channel dynamics, if not instantly changed, will undergo rapid changes, increasing the risks of other hazards such as flooding and debris flows due to a large influx of sediment. In all cases the hazards relating to migration may evolve due to major changes sediment flux.

Modelling of the threshold discharges required to overtop the Whataroa terraces resulted in estimated return periods ranging from 9 000 years for an event to flood the 1717 AD terrace, to 130 000 000 000 years for flooding of the 1620 AD terrace. These return periods are several orders of magnitude larger than Alpine Fault earthquake recurrence intervals that result in major sediment pulses that will drastically change channel dynamics, implying that inundation from river flooding under current channel conditions is highly unlikely. Therefore, with respect to flooding, any of the terraces are suitable for placing a drill rig. They have an extremely low chance of inundation. However, Swamp prone areas and ephemeral streams should be avoided, as they regularly have water bodies flowing through them during heavy rainfall periods.

Access to a majority of the site is easily achieved and will not play a major part in choosing the drill site. The old state highway, now a gravel road, provides access across the northern half of the terrace, to where the old state highway bridge used to be, illustrated on the Engineering Geology map in Appendix B. From here, a farm track extends about 500m south to where it is being eroded away at the terrace edge. These two tracks give access to a majority of the 1717 terrace, there are no other roads as such on the terrace, however there are a series of semi established pathways that are used for access throughout the farm. If any roads are to be developed, they should try to be along these pathways, as some of them are already semi developed on the most stable ground. This will also minimise additional environmental impact. Access routes have been suggested for each drilling location on Figure 4.4.

The summary hazard map from Chapter Three has been combined with Figure 4.2 to propose a range of favoured drill sites based on varied angle dips, whilst minimizing flood, erosion and sediment inundation hazards, and specifying access routes Figure 4.4.

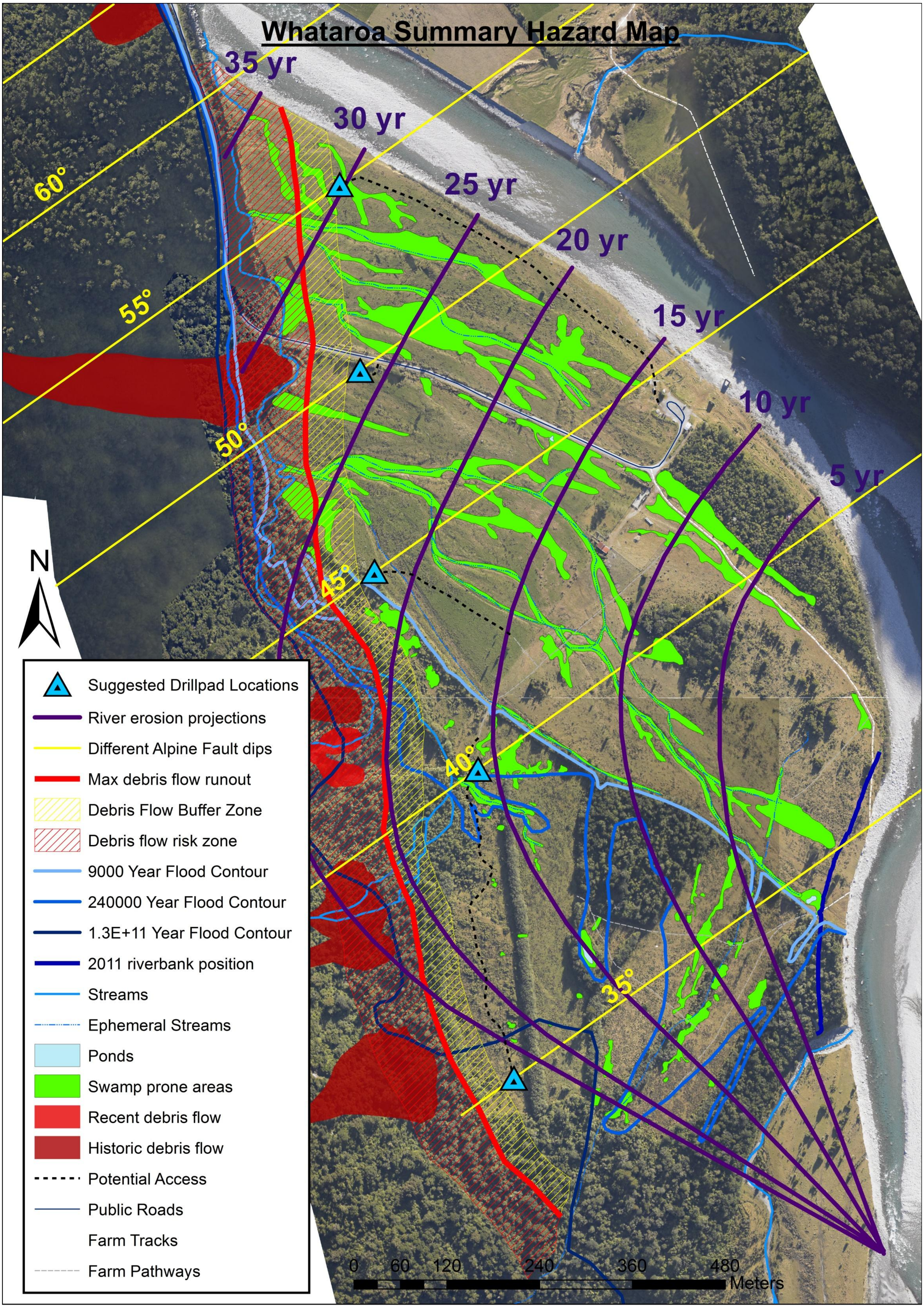


Figure 4.4 Summary hazard map combined with the map showing various fault dips. This map is used to identify one possible drill pad location for each 5° fault dip interval.

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5 Appendices

5.3 LiDAR

In September of 2010, GNS Science commissioned a light ranging and detection (LiDAR) survey along the central section of the Alpine Fault, to obtain a detailed elevation model of the fault, and identify the fault trace in more detail. The survey included 3 km up the Whataroa Valley from ~500m west of the range front to ~2500m upstream in order to include possible locations of the Whataroa River drilling site (Langridge, 2011).

The LiDAR was used right across this investigation for general mapping, debris flow identification, gaining slope data, and interpolating cross-sections for the river channel and debris flow profiles.

An uninterpreted LiDAR map of the area is presented in Appendix H.

5.4 Scala Penetrometer & Hand Auger

The scala penetrometer test is used to assess the strength of near surface materials (commonly 2-5 m depth). It involves measuring the resistance on a 20mm diameter steel cone in the ground by dropping a 9kg weight a from a height of 0.51m and recording the amount of penetration per blow (Dellow & Beetham, 2008).

The scala penetrometer was used to find a bearing load capacity for the terraces, however due to the bouldery nature of the river gravels, it could not penetrate more than 50-100mm before hitting refusal on a large stone. Other options to obtain bearing load capacity measurements for the site were looked into, such as plate load tests. However this is an expensive and equipment intensive operation that would have not been economical to the project.

Hand auguring was also attempted, however for the same reasons (resistance from boulders), it was unsuccessful. Testpitting was then looked at to reveal a subsurface profile, this is discussed later in the chapter.

5.5 Facelog

Along the eroding southern edge of the terrace, next to the modern Whataroa River channel there is a 390m long gravel face, showing a fresh and actively eroding outcrop. A face log of this was completed to map in detail the different lithologies present at the site and identify their characteristics and relative ages.

The facelog was split into four ~100 m sections in Appendix C.

Limitations

Issues with the face log were:

(1) Stitching. Due to the terrace exposure being so wide the photos had to be taken from a number of different locations. The stitching program drastically skewed the outcrop to accommodate this. The cause was the trees in the background appearing in relatively different positions in different photos. To fix this, all background vegetation had to be blocked out of the photos.

(2) Scale. Also as a result of taking the photos from different locations, these ended up being different distances from the face. Therefore different photos were different scales, and measurements sprayed onto the face were distorted. This caused the image of the terrace surface which is in reality, flat, to curve and appear uneven. To reduce this effect, the Face log was split into four different sections of about 100m each.

Therefore, the facelog has some distortion. There also would have been some errors when physically measuring the face, the uneven and bouldery surface would have caused some inconsistencies between each 10 m mark. A second set of photos were going to be taken with all of these issues in mind, however, the original ones were taken soon after a heavy rain fall event that had scoured a majority of the colluvium away. This provided much more exposure of the gravel face, particularly of the lower unit.

5.6 Testpitting

During January – February 2011, the Whataroa Detailed University Seismic Imaging Experiment (WhataDUSIE) project was undertaken in the Whataroa Valley. This consisted of placing explosives every 20-30 metres along a shot line up the valley, illustrated on the Whataroa testpits image in section 2.3. An excavator was brought in to dig a hole at each spot to ~1.5m depth to place the explosives. Every hole on the site was logged to document the subsurface material.

It should be noted that the primary purpose of these holes was for placing explosives, not for geotechnical reasons, therefore they were not terminated upon refusal or any particular target depth, and the spoil of different soil units were often mixed together. However it did provide some insight into the subsurface stratigraphy and composition of the fan.

The testpit logs can be found in Appendix D.

Limitations

As the testpits were done over the space of one day, they were very rushed. There was not sufficient time to get a lot of detail out of each testpit. It was possibly more beneficial to select a smaller number of the holes and do them in more detail rather than log every hole.

Also, because the holes were being dug for a seismic survey, they were located according to where the explosives needed to be. If more subsurface investigation is to be carried out, it should be spread over the fan more and cove more surfaces. None of the holes dug were on the 1620 terrace, so data is missing for that part of the investigation area.

5.7 MASW – Multi Channel Analysis of Surface Waves

The two primary goals for the MASW were to (1) gain stiffness data on the materials, as scala penetrometer tests failed, due to the coarse nature of the gravels at the site and (2) identify if bedrock is present in the near surface (<30m). Depth to bedrock is important for identifying how deep casing should be installed in the borehole. Casing is a PVC or metal pipe put down the hole around the drill rods, to prevent borehole failure in the soil or loose rock sections of the borehole.

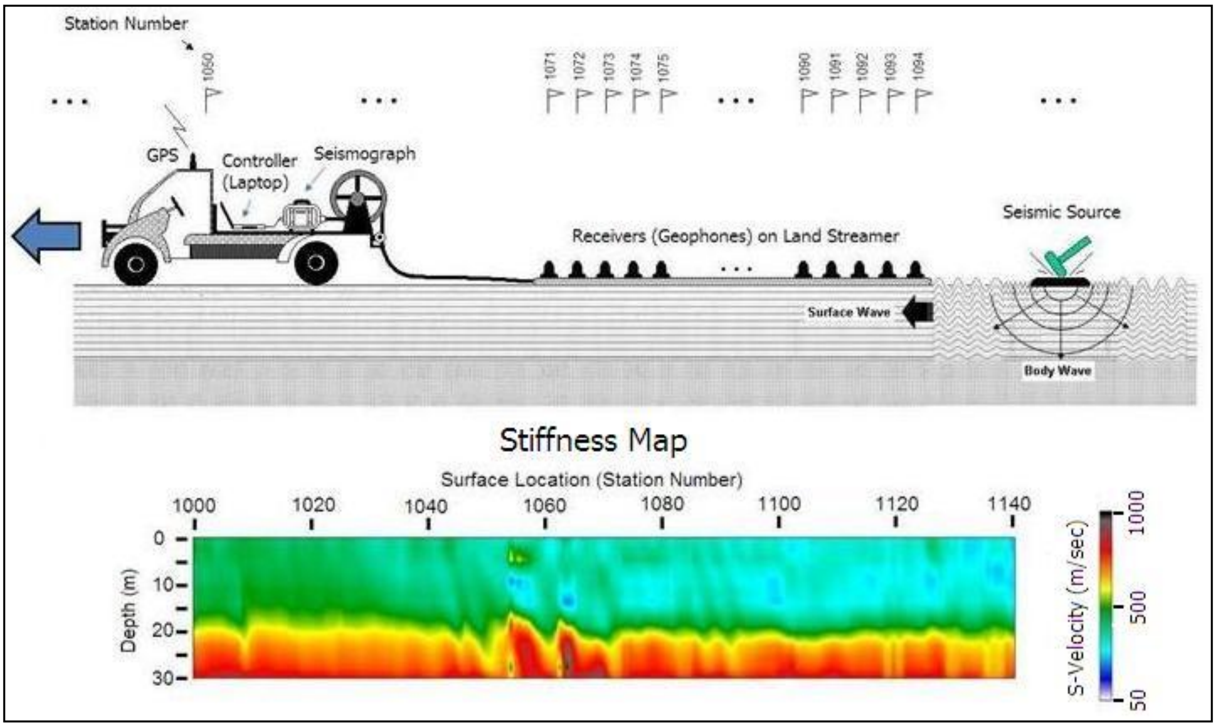


Figure 5.1 Basic MASW setup and example of the image it produces. (MASW.com)

In most seismic surveys two-thirds or more of the source energy is converted into Rayleigh waves, seen as ground roll. Ground roll can be defined as a type of noise generated by a surface wave, typically made up of low velocity and frequency, large amplitude waves (Schlumberger, 2011). This is often seen as noise in body wave surveys, such as reflection and refraction, however, MASW uses properties of ground roll to identify near surface elastic characteristics. The key property for this is signal dispersion, where each wave length travels at a different speed, i.e. longer wavelengths travel faster and shorter wavelengths travel slower reflecting elastic properties from further and closer points to the energy source. Rayleigh waves are confined to the air/earth interface and disperse at different velocities presenting a dispersion curve, these dispersion curves are inverted to produce a shear wave velocity profile. Shear-wave velocity is proportional to the shear modulus which directly indicates rigidity of a material (Xia, Park, & Miller, 1997). Therefore, the shear wave velocity profile obtained from ground roll can be used as a near surface stiffness profile, providing a useful, non-invasive tool in geotechnical studies (Park, Miller, & Xia, 1999).

Figure 5.2: MASW Setup (Photos courtesy of Greg DePascale)

Table 5.1 Parameters used for each of the MASW lines.

Survey line	1	2	3	AFa	AFb
Acquisition	24	13	24	24	24
Array dimension	23	12	23	23	23
Near offset (m)	15	20	20	20	15
Geophone Spacing (m)	1	1	1	1	1
Geophone Frequency (Hz)	8	8	8	8	8
Shot spacing	5	5	5	5	5
Sampling interval (ms)	0.5	0.5	0.5	0.5	0.5
Recording time (s)	2	2	2	2	2
Number of records	12	21	23	42	25
Survey length	55	100	110	205	120

The setup details for each survey are outlined in

Table 5.1. The source used to generate ground roll was a sledge hammer on a metal plate, this was stacked six times to reduce the noise from surrounding sources such as the river and distant cars on the state highway.

The uninterpreted profile and location of each MASW line can be found in Appendix E.

Limitations

Due to availability of gear and the required personnel this investigation was undertaken very early in the project. If this were to be done again, more thought and preliminary investigation should go into where the surveys are conducted. It was the first field work to be done and was carried out on the first site visit. It was in a localised area about 1.5 – 1.7km from the state highway bridge, at first thought to be an ideal spot for a drill rig. However at this point there had not been any other investigation done. After identifying the rivers potential to rapidly erode large segments of the southern river bank, much of the area surveyed with MASW is now gone and the rest of the survey area is deemed unsuitable for a project site as it too could potentially be gone in a matter of years.

Terrain was an issue during the data collection stage. The bouldery surface limited where the truck could go and it would be impractical to drag this survey by hand. The small channels also caused problems when scouting out survey lines as it limited the length of continuous surveying and at times proved difficult for the truck, during one survey the truck got stuck, causing the survey to be cancelled.

One issue identified during the processing stage was that we attempted to get too much penetration in the data. The metal plate source we were using emitted relatively high frequency waves, because of the large offset from the source to achieve deeper penetration much of the high frequency information was lost and not recorded, lowering the quality of the data. We would have been better to go with a shorter 10m offset to gain more detail. Or, having kept the same offset for penetration and used a different source that emits lower frequencies. A method that has worked on surveys since this one is to use the hammer straight onto the soil, without the plate.

During the analysis stage, comparing lines one and two to the riverbank outcrop, an issue was encountered with the scaling of the photos, similar to when doing the facelog. Due to the photos being taken from different points their sprayed on scales were different, an average of all the scales was used to minimise the distortion.

Overall this was a good method to use for this project, it provided a good balance of subsurface imaging and geotechnical information, by making a few changes to the method, a much better, more extensive data set could be obtained. However, compared to other geophysical techniques such as GPR, it is a very time consuming, labour intensive job that needs a number of people to undertake.

The Alpine Fault data set was collected very early in the project, but not processed until very late, leaving no opportunity for any follow up investigation. To identify the sub surface features better, a GPR survey across the area would be valuable.

5.8 GPR – Ground Penetrating Radar

GPR uses reflected signals from electromagnetic radar pulses to detect structures, bedding features and foreign objects such as buried services in the ground to gain an image of the subsurface. A high frequency radio wave is transmitted into the ground, propagation of the radar signal depends on the high frequency electrical properties of the ground, when the energy hits a boundary where two mediums have different properties a signal is reflected and picked up by the receiver (Davis & Annan, 1989). As the conductivity of a soil increases, the depth of penetration for GPR decreases, therefore, in coarse gravel with little or no clay as seen in the Whataroa Valley, it was expected to achieve up to 30 m depth.

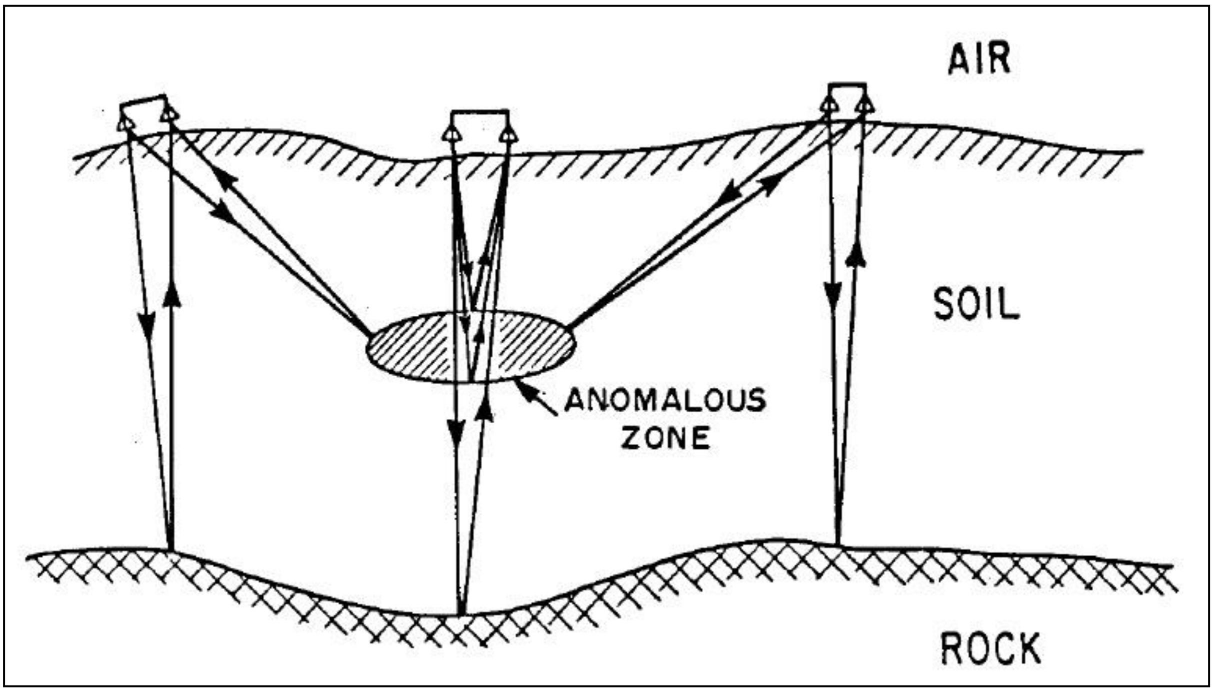


Figure 5.3: GPR - Conceptual illustration of the radar being used in the reflection profiling mode on soil over bedrock. (Davis & Annan, 1989)

The goal of this investigation was to identify depth to bedrock. The spread of GPR surveys, illustrated on the Whataroa Geophysical Investigations Map in Appendix B, was to try and identify a dip or trend on the bedrock contact if it was found. There is a long line broken up into a few separate surveys due to fences and roads that trend north-south and stretch across the whole fan, and another three lines spread out to cover the extremities of the fan.

Figure 5.4 GPR Setup of the 50MHz GPR antennas

The procedure carried out was as follows: 50 MHz antennas were used, as these were the lowest frequency antennas available to practically get the most depth. They were mounted on a sled with 2 m separation and dragged along slowly for continuous collection. A minimum of 20 points were collected every 10 m. Fiducial markers were set every 10 m. A

CMP (Common Mid Point survey) was conducted at each area a line was recorded, this gave values varying from 130 m/µs to 190 m/µs giving an average of 160 m/µs which was used for the processing. All of the GPR lines were processed using EKKOView Deluxe with topographic correction, multiple different gain settings were used to highlight different features.

The uninterpreted profiles and location of each GPR line can be found in Appendix F.

Limitations

Overall the GPR ran smoothly, the major issue was how the sled moved over the terrane. Uneven surfaces, boulders, tree stumps and thick reeds often got caught, holding up data collection and likely adding extra recordings in unwanted positions. It would be better to have three people for this process and use the step function, and take single readings at exact measured positions.

Appendix A – Methods

5.1 Field Mapping

Field mapping was used to produce a series of geomorphological and engineering geology maps, which are presented in Appendix B. An initial geomorphic map was drafted using aerial photos and topographic maps before going into the field. Field mapping was conducted to provide more information and identify any features that may be changing or evolving over time. Important features that were recorded were terraces, landslides/debris flows (relic and active), water channels (ephemeral and continuous), swamps and low-lying areas (particularly their difference in size between summer and winter).

Cultural features were also recorded such as buildings, fences, roads, farm tracks, walking tracks that are often used by the public and any other infrastructure.

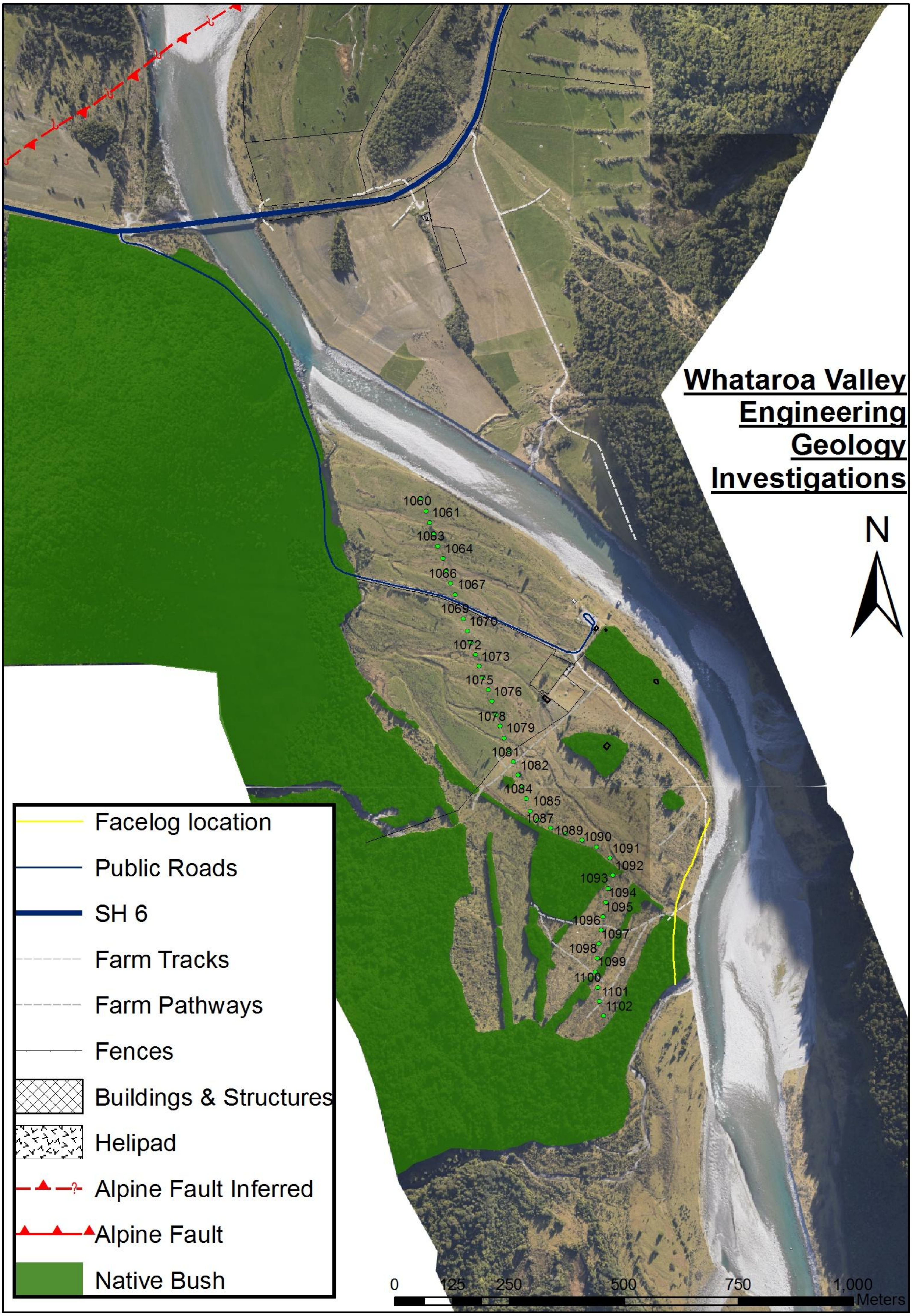
5.2 Differential GPS (DGPS)

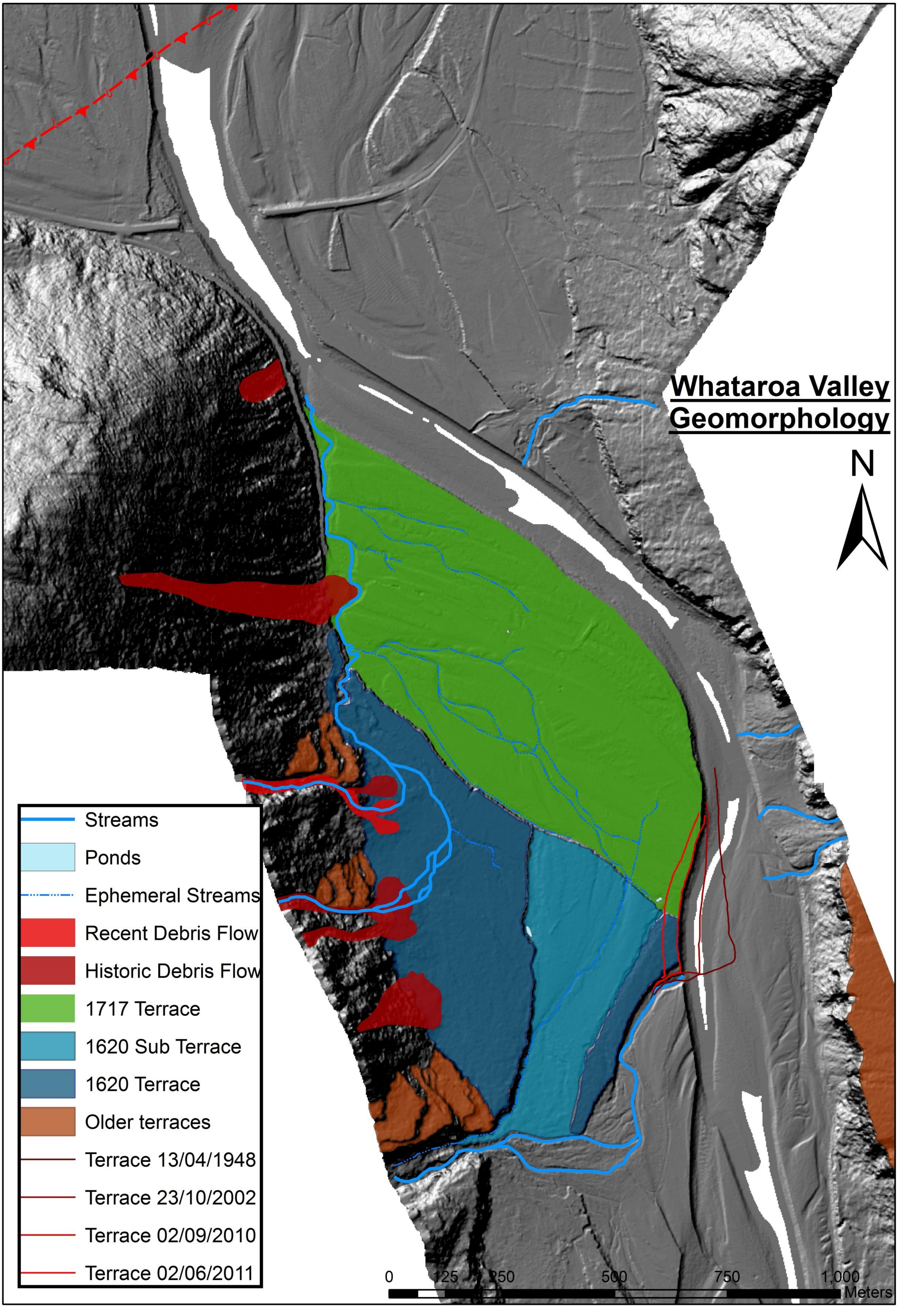
A Differential GPS survey was carried out over two weeks during June 2010. To create a topographic base map for the study and accurately map in geomorphic features such as terraces etc. An Order 2 geodetic marker is located ~5km from the Whataroa River site in the town of Whataroa. One Trimble GeoXH with a Zephyr antenna was setup at this location as a base station, and another GeoXH was used as a hand held rover unit to survey the area. The area was walked over in a grid pattern of approximately 10-30m spacing to maximise coverage. Grid size depended on the variability in terrane, large flat areas did not need as high concentration of points. Any other features such as the riverbank and terraces were walked along independently to increase the resolution of important features.

Upon completion of the survey, the data was differentially corrected twice using Trimble GPS Pathfinder Office. First the recorded base station data was used, and second the Hokitika and Mt John observatory base stations combined data. The quality of the Hokitika and Mt John stations data provided more accurate data than the base station data collected in Whataroa, so this was used instead.

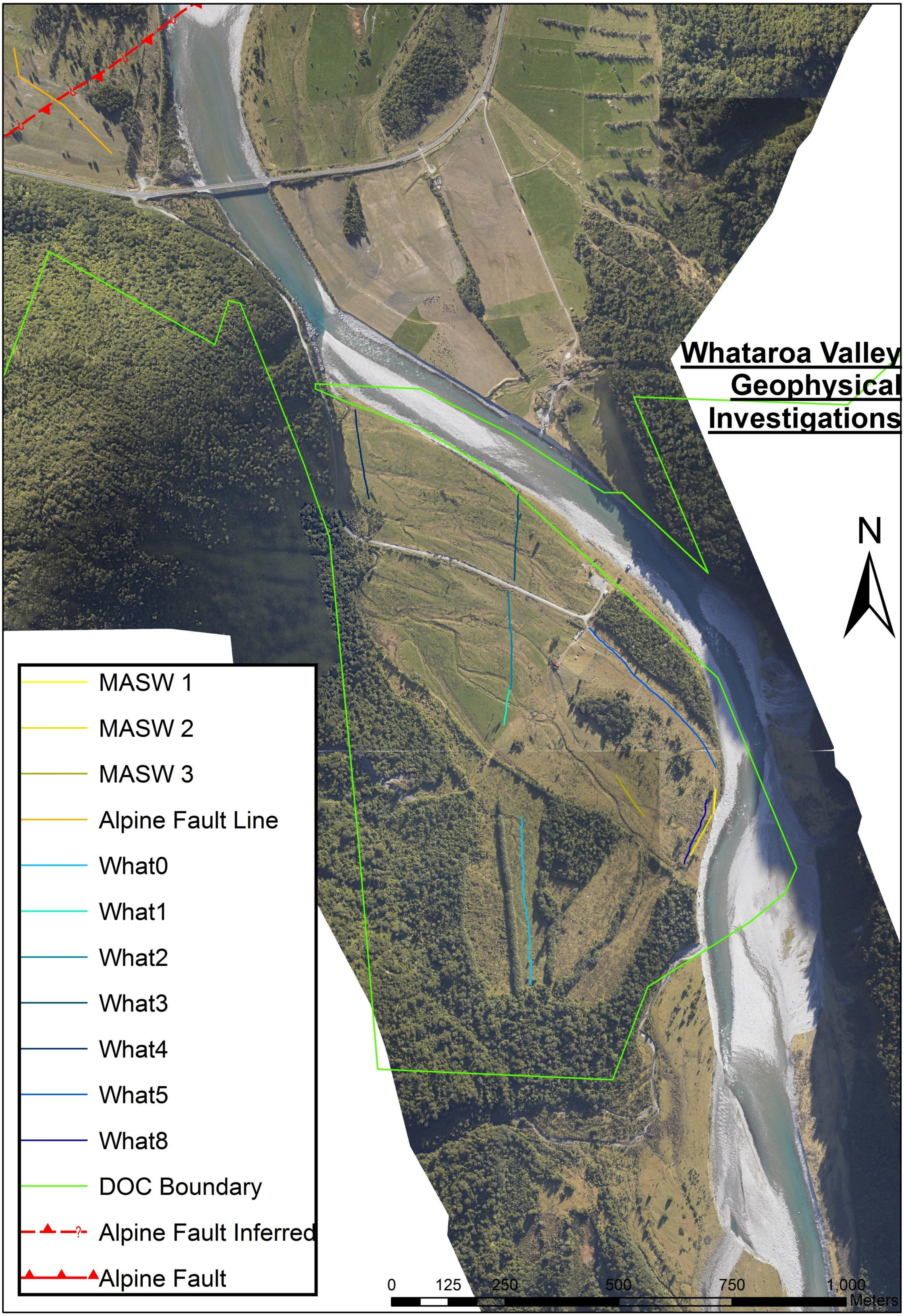
After this exercise there was no need to setup a base station for any further DGPS work because the Hokitika and Mt John stations provided sufficient data for processing. The DGPS was used numerous times to survey the southern riverbank from June 2010 and September 2011 to better constrain the short-term lateral incision rate.

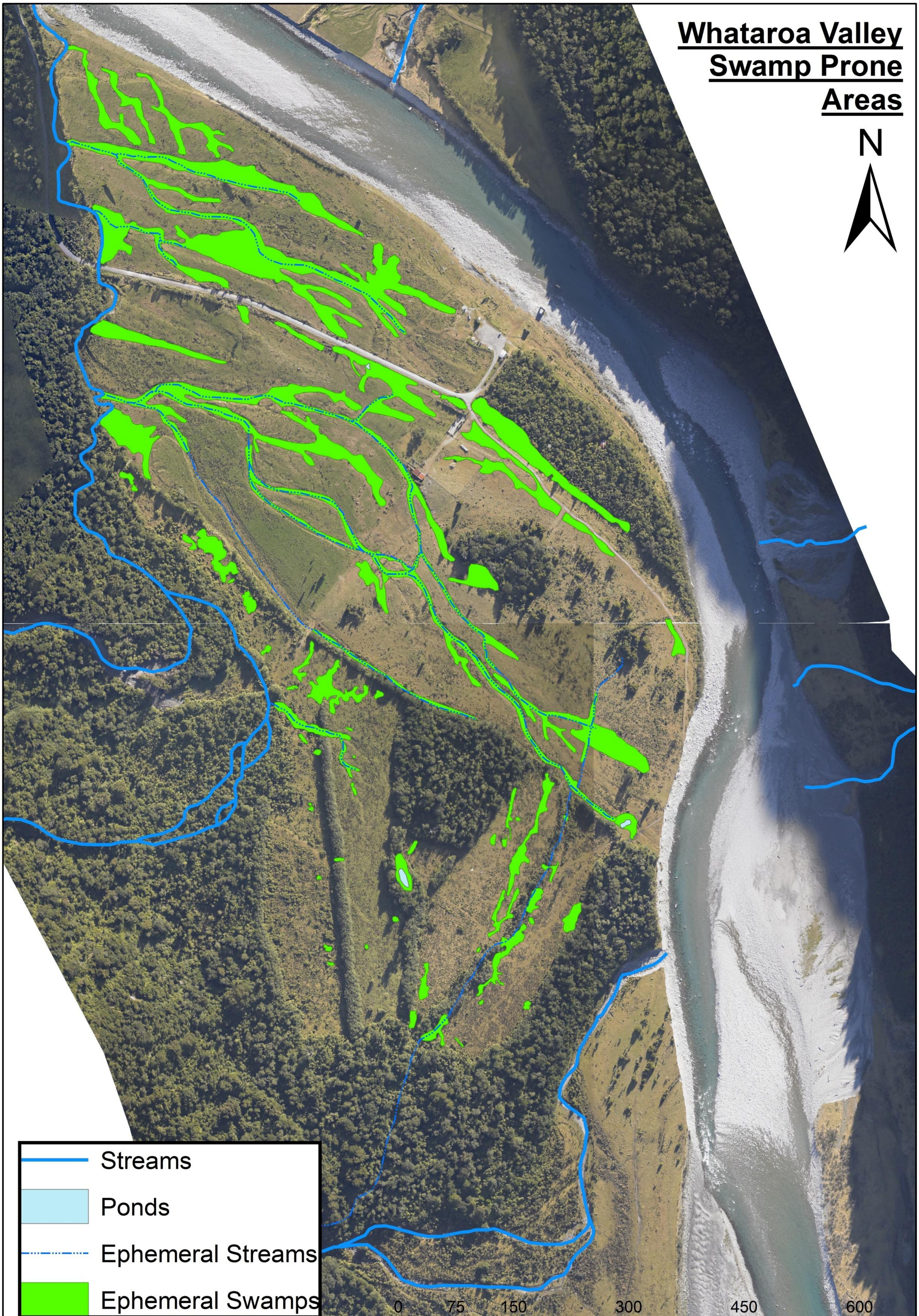
Appendix B – Maps


Whataroa Valley
Engineering
Geology
Investigations
N
1060
1061
1063
1064
1066
1067
1069
1070
1072
1073
1075
1076
1078
1079
1081
1082
1084
1085
1087
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
Facelog location
Public Roads
SH 6
Farm Tracks
Farm Pathways
Fences
Buildings & Structures
Helipad
Alpine Fault Inferred
Alpine Fault
Native Bush
0
125
250
500
750
1,000
Meters

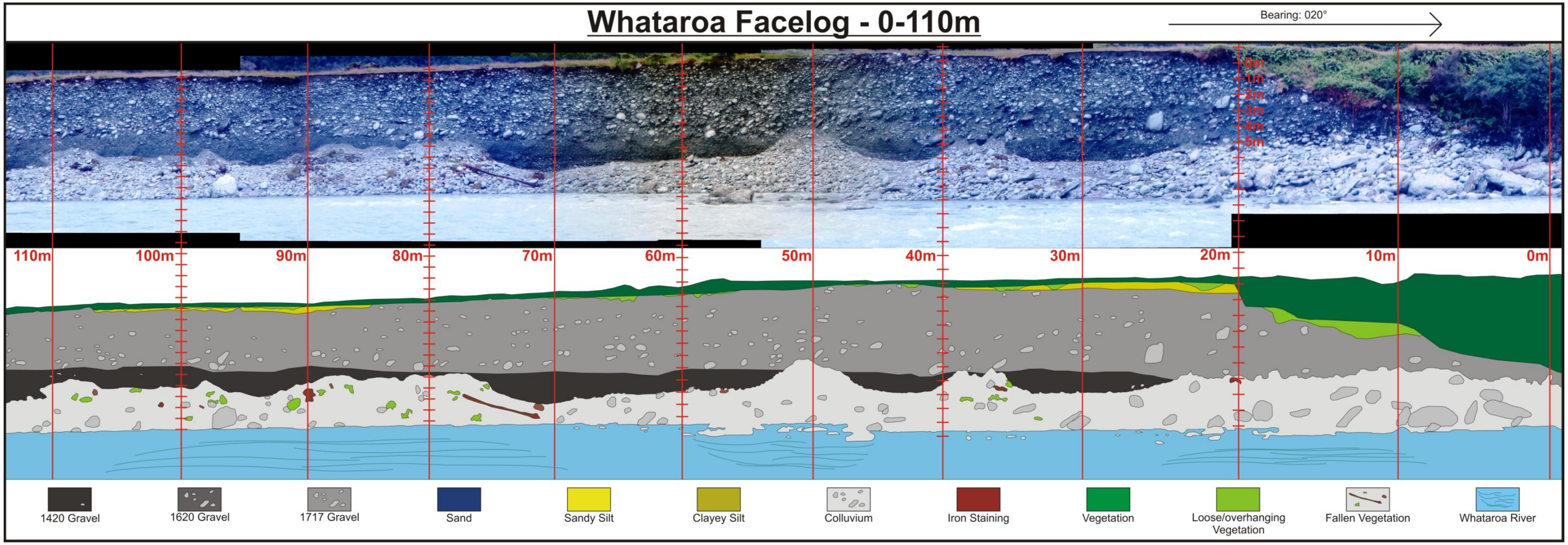


Whataroa Valley Geomorphology
N
Streams
Ponds
Ephemeral Streams
Recent Debris Flow
Historic Debris Flow
1717 Terrace
1620 Sub Terrace
1620 Terrace
Older terraces
Terrace 13/04/1948
Terrace 23/10/2002
Terrace 02/09/2010
Terrace 02/06/2011
0
125
250
500
750
1,000
Meters

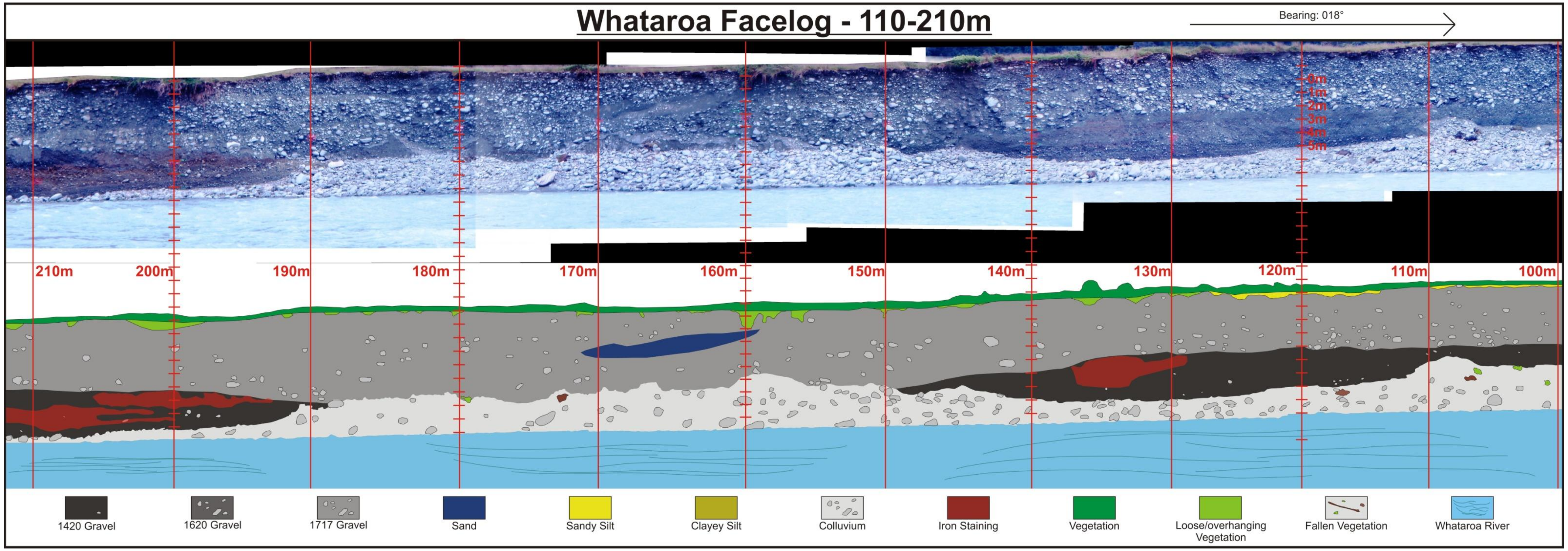

Whataroa Valley Geophysical Investigations
N
MASW 1
MASW 2
MASW 3
Alpine Fault Line
What0
What1
What2
What3
What4
What5
What8
DOC Boundary
Alpine Fault Inferred
Alpine Fault
0
125
250
500
750
1,000
Meters

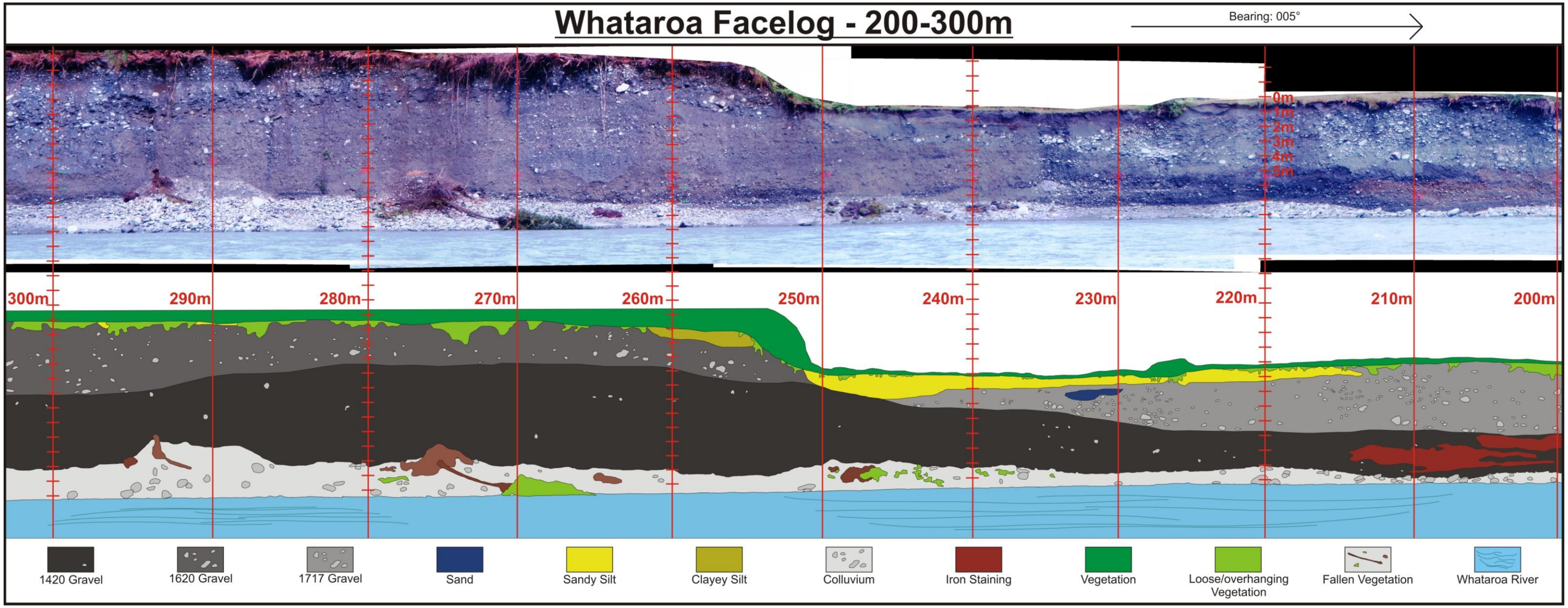

Whataroa Valley
Swamp Prone
Areas
N
Streams
Ponds
Ephemeral Streams
Ephemeral Swamps
0
75
150
300
450
600
Meters

Appendix C – Face Log

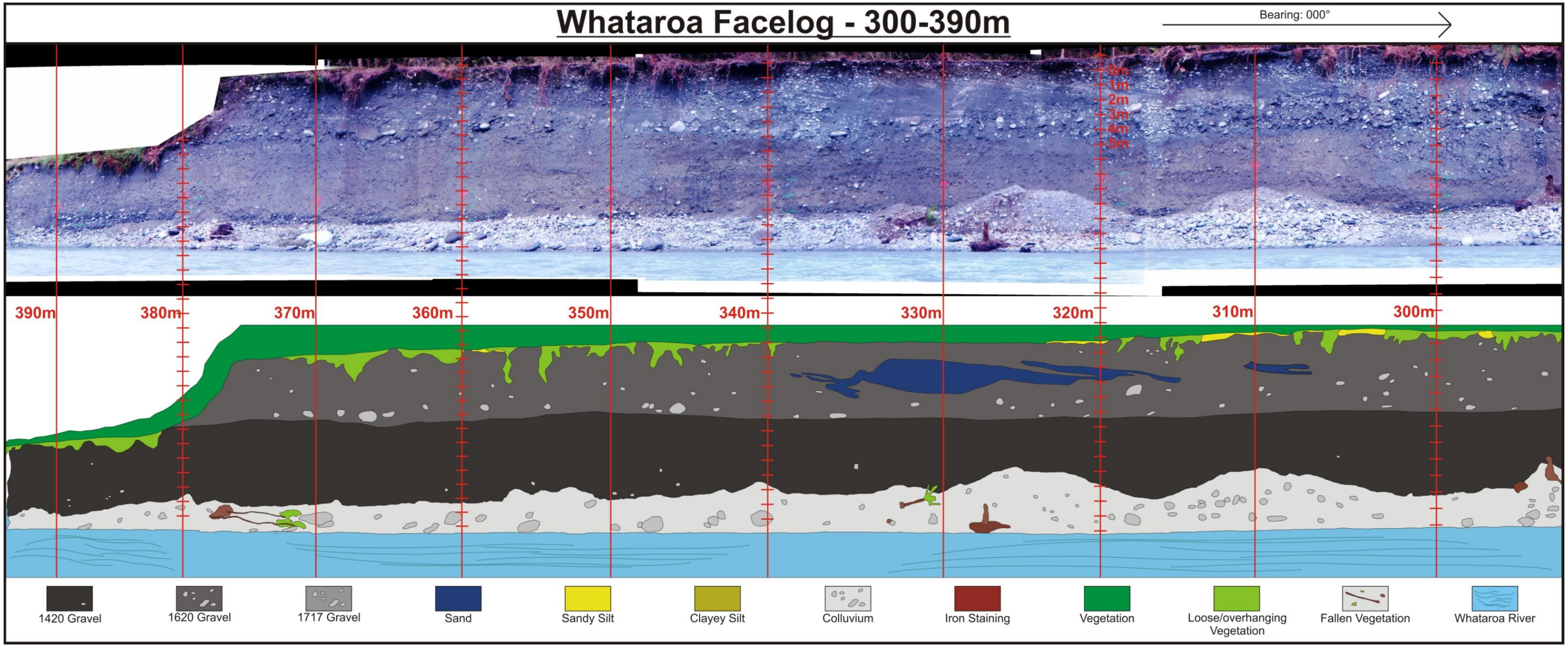


Whataroa Facelog - 0-110m
Bearing: 020°
0m
1m
2m
3m
4m
5m
110m
100m
90m
80m
70m
60m
50m
40m
30m
20m
10m
0m
1420 Gravel
1620 Gravel
1717 Gravel
Sand
Sandy Silt
Clayey Silt
Colluvium
Iron Staining
Vegetation
Loose/overhanging Vegetation
Fallen Vegetation
Whataroa River


Whataroa Facelog - 110-210m
Bearing: 018°
0m
1m
2m
3m
4m
5m
210m
200m
190m
180m
170m
160m
150m
140m
130m
120m
110m
100m
1420 Gravel
1620 Gravel
1717 Gravel
Sand
Sandy Silt
Clayey Silt
Colluvium
Iron Staining
Vegetation
Loose/overhanging Vegetation
Fallen Vegetation
Whataroa River



Whataroa Facelog - 200-300m
Bearing: 005°
0m
1m
2m
3m
4m
5m
300m
290m
280m
270m
260m
250m
240m
230m
220m
210m
200m
1420 Gravel
1620 Gravel
1717 Gravel
Sand
Sandy Silt
Clayey Silt
Colluvium
Iron Staining
Vegetation
Loose/overhanging Vegetation
Fallen Vegetation
Whataroa River



Whataroa Facelog - 300-390m
Bearing: 000°
0m
1m
2m
3m
4m
5m
390m
380m
370m
360m
350m
340m
330m
320m
310m
300m
1420 Gravel
1620 Gravel
1717 Gravel
Sand
Sandy Silt
Clayey Silt
Colluvium
Iron Staining
Vegetation
Loose/overhanging Vegetation
Fallen Vegetation
Whataroa River

Appendix D – Testpit Logs

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1059 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0 **REMARKS:**

EOH (m): 1.3

FROM (m): 0		**TO (m):** 1.3	Photo
TERTIARY COMPONENT	SECONDARY COMPONENT Gravelly	PRIMARY COMPONENT Sand	
MODIFIER with	MINOR COMPONENT Cobbles & Boulders	PLASTICITY Non	
PARTICLE SIZE Medium sand	MODIFIER to	PARTICLE SIZE Coarse sand	
PARTICLE SHAPE Subrounded	MODIFIER to	PARTICLE SHAPE angular	
COLOUR 1 Grey	COLOUR 2	MOISTURE Moist	
CONSISTENCY / DENSITY Loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS Rootlets down to 200mm Boulders up to 400mm in size			

FROM (m):		**TO (m):**	Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

FROM (m):		**TO (m):**	Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1060 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.7

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

Rootlets down to 500mm,
Topsoil grading to sand within 100mm

Photo

FROM (m): 0.7 **TO (m):** 1.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
With	Cobbles & Boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium Sand	to	Coarse Sand
Fine Gravel	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	Augular

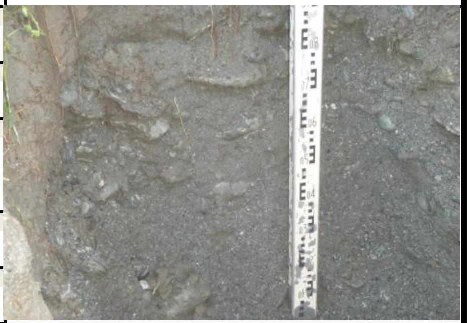
COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders up to 500mm in size

Photo



FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1061 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.3

FROM (m): 0 **TO (m):** 0.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Fine sand	to	Medium sand

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

Rootlets down to 200mm,

Topsoil grading to sand within 100mm

Photo

FROM (m): 0.5 **TO (m):** 1.3

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
With	Cobbles & Boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium Sand	to	Coarse Sand
Fine Gravel	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	Augular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1062 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
trace	cobbles & boulders	Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Fine sand	to	coarse sand

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

Rootlets down to 200mm, boulders up to 200mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1063 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:** next to a swamp with sitting water

EOH (m): 1.3

FROM (m): 0 **TO (m):** 1.3

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	trace
MINOR COMPONENT	boulders, cobbles & gravel
PLASTICITY	Non
PARTICLE SIZE	Fine sand
MODIFIER	to
PARTICLE SIZE	coarse sand
PARTICLE SHAPE	Subrounded
MODIFIER	to
PARTICLE SHAPE	angular
COLOUR 1	Grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	Loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	water table at 1.2m depth? The hole was dug the previous day and it rained over night

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1064 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.3

FROM (m): 0 **TO (m):** 1.3

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
trace	boulders, cobbles	Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	coarse sand

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	sub angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

cobbles up to 50mm in size,
topsoil grade to sand within 100mm

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1065 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.1

FROM (m): 0 **TO (m):** 1.1

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Coarse Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
trace	Gravel & cobbles	Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
coarse sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Subrounded	to	angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

cobbles up to 50mm in size,

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1066 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Silty	Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Fine Sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub angular		

COLOUR 1	COLOUR 2	MOISTURE
brownish	grey	Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

rootlets to 500mm

Photo

FROM (m): 0.6 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
Sandy	Bouldery	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand
Fine gravel	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders to 400mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1067 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.7

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		Non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium Sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub angular	to	Sub rounded

COLOUR 1	COLOUR 2	MOISTURE
grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
Loose		

ADDITIONAL COMMENTS

Photo

FROM (m): 0.7 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
Sandy	Bouldery	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand
Fine gravel	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders to 400mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1069 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.5

TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT: Sand
MODIFIER:	MINOR COMPONENT:	PLASTICITY: Non
PARTICLE SIZE: Medium Sand	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE: Sub angular	MODIFIER: to	PARTICLE SHAPE: Sub rounded
COLOUR 1: grey	COLOUR 2:	MOISTURE: Moist
CONSISTENCY / DENSITY: Loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS: Rootlets down to 600mm		

Photo

FROM (m): 0.5 **TO (m):** 1.5

TERTIARY COMPONENT: Sandy	SECONDARY COMPONENT: Bouldery	PRIMARY COMPONENT: Gravel
MODIFIER:	MINOR COMPONENT:	PLASTICITY: non
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse Gravel
PARTICLE SHAPE: Sub rounded	MODIFIER: to	PARTICLE SHAPE: Sub angular
COLOUR 1: grey	COLOUR 2:	MOISTURE: moist
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS: Boulders to 600mm in size		

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT:
MODIFIER:	MINOR COMPONENT:	PLASTICITY:
PARTICLE SIZE:	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:
COLOUR 1:	COLOUR 2:	MOISTURE:
CONSISTENCY / DENSITY:	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS:		

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1070 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0.1 **TO (m):** 1.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
Sandy	Bouldery	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand
Fine gravel	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders to 700mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1071 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.4

FROM (m): 0.2	**TO (m):** 1.4		**Photo**
TERTIARY COMPONENT: Sandy	SECONDARY COMPONENT: Bouldery	PRIMARY COMPONENT: Gravel	
MODIFIER:	MINOR COMPONENT:	PLASTICITY: non	
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse Gravel	
PARTICLE SHAPE: Sub rounded	MODIFIER: to	PARTICLE SHAPE: Sub angular	
COLOUR 1: grey	COLOUR 2:	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:	
ADDITIONAL COMMENTS: Boulders to 700mm in size Rootlets down to 300mm			

FROM (m):	**TO (m):**		**Photo**
TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT:	
MODIFIER:	MINOR COMPONENT:	PLASTICITY:	
PARTICLE SIZE:	MODIFIER:	PARTICLE SIZE:	
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:	
COLOUR 1:	COLOUR 2:	MOISTURE:	
CONSISTENCY / DENSITY:	MODIFIER:	CONSISTENCY / DENSITY:	
ADDITIONAL COMMENTS:			

FROM (m):	**TO (m):**		**Photo**
TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT:	
MODIFIER:	MINOR COMPONENT:	PLASTICITY:	
PARTICLE SIZE:	MODIFIER:	PARTICLE SIZE:	
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:	
COLOUR 1:	COLOUR 2:	MOISTURE:	
CONSISTENCY / DENSITY:	MODIFIER:	CONSISTENCY / DENSITY:	
ADDITIONAL COMMENTS:			

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1072 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.8

FROM (m): 0 **TO (m):** 1.8

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Coarse Sand
MODIFIER	Trace
MINOR COMPONENT	Boulders & Cobbles
PLASTICITY	non
PARTICLE SIZE	Medium sand
MODIFIER	to
PARTICLE SIZE	Coarse sand
PARTICLE SHAPE	Sub rounded
MODIFIER	to
PARTICLE SHAPE	Sub angular
COLOUR 1	grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Only one boulder - 600mm

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1073 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: North end of the Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.7

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Medium sand
MODIFIER	to
PARTICLE SIZE	Coarse sand
PARTICLE SHAPE	Sub rounded
MODIFIER	to
PARTICLE SHAPE	Sub angular
COLOUR 1	grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 700mm

Photo

FROM (m): 0.7 **TO (m):** 1.6

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Boulders & cobbles
PLASTICITY	non
PARTICLE SIZE	Fine sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub angular
MODIFIER	to
PARTICLE SHAPE	Sub rounded
COLOUR 1	grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders up to 300mm in size.

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1074 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.4

FROM (m): 0 **TO (m):** 0.4

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Medium sand
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	Sub rounded
MODIFIER	to
PARTICLE SHAPE	Sub angular
COLOUR 1	grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 700mm

Photo

FROM (m): 0.4 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Boulders & cobbles
PLASTICITY	non
PARTICLE SIZE	Med sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub angular
MODIFIER	to
PARTICLE SHAPE	Sub rounded
COLOUR 1	grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders up to 600mm in size.

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1075 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
grey		moist

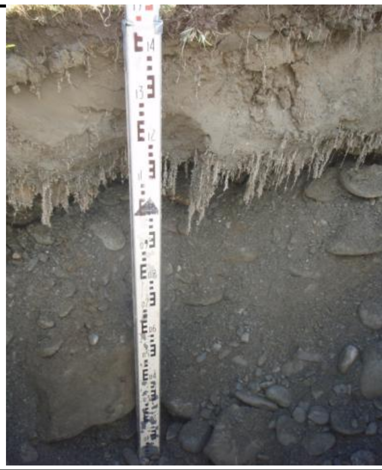
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Rootlets to 600mm

Slight brown streaks in sand.

Photo



FROM (m): 0.5 **TO (m):** 1.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Boulders & cobbles	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Med sand	to	Coarse sand
Fine gravel	to	Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub angular	to	Sub rounded

COLOUR 1	COLOUR 2	MOISTURE
grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders up to 500mm in size.

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1076 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.5

FROM (m): 0	**TO (m):** 0.5	
TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT: Sand
MODIFIER:	MINOR COMPONENT:	PLASTICITY: non
PARTICLE SIZE: Medium sand	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE: Sub rounded	MODIFIER: to	PARTICLE SHAPE: Sub angular
COLOUR 1: grey	COLOUR 2:	MOISTURE: moist
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS: Rootlets to 600mm		

Photo

FROM (m): 0.5	**TO (m):** 1.5	
TERTIARY COMPONENT:	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel
MODIFIER: with	MINOR COMPONENT: Boulders & cobbles	PLASTICITY: non
PARTICLE SIZE: Med sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel
PARTICLE SHAPE: Sub angular	MODIFIER: to	PARTICLE SHAPE: Sub rounded
COLOUR 1: grey	COLOUR 2:	MOISTURE: Moist
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS: Boulders up to 500mm in size.		

Photo

FROM (m):	**TO (m):**	
TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT:
MODIFIER:	MINOR COMPONENT:	PLASTICITY:
PARTICLE SIZE:	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:
COLOUR 1:	COLOUR 2:	MOISTURE:
CONSISTENCY / DENSITY:	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS:		

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1077 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

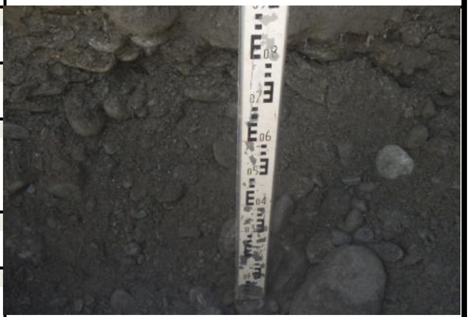
EOH (m): 1.6

FROM (m): 0	**TO (m):** 0.7		
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT: Sand	
MODIFIER	MINOR COMPONENT		PLASTICITY: non
PARTICLE SIZE: Medium sand	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE: Sub rounded	MODIFIER: to	PARTICLE SHAPE: Sub angular	
COLOUR 1: grey	COLOUR 2	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Rootlets to 900mm			

Photo

FROM (m): 0.7	**TO (m):** 1.6		
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Boulders & cobbles		PLASTICITY: non
PARTICLE SIZE: Med sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel	
PARTICLE SHAPE: Sub angular	MODIFIER: to	PARTICLE SHAPE: Sub rounded	
COLOUR 1: grey	COLOUR 2	MOISTURE: Moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Boulders up to 400mm in size.			

Photo



FROM (m):	**TO (m):**		
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT		PLASTICITY
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1078 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.4

FROM (m): 0 **TO (m):** 0.7

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
Sandy	Cobbley	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse Sand
Fine	to	Coarse Gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
grey		wet

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders to 700mm

Swamp flowing into hole, water table at 1.3m?

FROM (m): **TO (m):**

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

FROM (m): **TO (m):**

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1079 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.7

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub rounded	to	Sub angular

COLOUR 1	COLOUR 2	MOISTURE
Brownish	Grey	moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Rootlets to 800mm

Photo

FROM (m): 0.7 **TO (m):** 1.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Boulders & cobbles	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Med sand Fine gravel	to to	Coarse sand Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub angular	to	Sub rounded

COLOUR 1	COLOUR 2	MOISTURE
grey		Moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders up to 500mm in size.

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1080 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.4

FROM (m): 0 **TO (m):** 0.2

TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT: Silt
MODIFIER:	MINOR COMPONENT:	PLASTICITY: non
PARTICLE SIZE: fine	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:
COLOUR 1: Grey	COLOUR 2:	MOISTURE: moist
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS:		

Photo

FROM (m): 0.2 **TO (m):** 1.4

TERTIARY COMPONENT:	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel
MODIFIER: with	MINOR COMPONENT: Boulders & cobbles	PLASTICITY: non
PARTICLE SIZE: Med sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel
PARTICLE SHAPE: Sub angular	MODIFIER: to	PARTICLE SHAPE: Sub rounded
COLOUR 1: grey	COLOUR 2:	MOISTURE: Moist
CONSISTENCY / DENSITY: loose	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS: Boulders up to 500mm in size.		

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT:	SECONDARY COMPONENT:	PRIMARY COMPONENT:
MODIFIER:	MINOR COMPONENT:	PLASTICITY:
PARTICLE SIZE:	MODIFIER:	PARTICLE SIZE:
PARTICLE SHAPE:	MODIFIER:	PARTICLE SHAPE:
COLOUR 1:	COLOUR 2:	MOISTURE:
CONSISTENCY / DENSITY:	MODIFIER:	CONSISTENCY / DENSITY:
ADDITIONAL COMMENTS:		

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1081 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

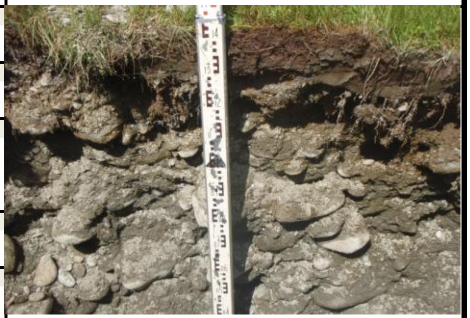
TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.1

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Silt
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	fine
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo



FROM (m): 0.1 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Boulders & cobbles
PLASTICITY	non
PARTICLE SIZE	Med sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub angular
MODIFIER	to
PARTICLE SHAPE	Sub rounded
COLOUR 1	grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders up to 600mm in size. Rootlets to 300mm

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1082 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.6

FROM (m): 0	TO (m): 1.6			
TERTIARY COMPONENT		SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Cobbles & Boulders			PLASTICITY: non
PARTICLE SIZE: Med sand / Fine gravel		MODIFIER: to / to	PARTICLE SIZE: Coarse sand / Coarse gravel	
PARTICLE SHAPE: Sub-rounded		MODIFIER: to	PARTICLE SHAPE: Sub-angular	
COLOUR 1: Grey	COLOUR 2		MOISTURE: moist	
CONSISTENCY / DENSITY: loose		MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Boulders up to 600mm in size; Rootlets to 400mm				

Photo

FROM (m):	TO (m):			
TERTIARY COMPONENT		SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT			PLASTICITY
PARTICLE SIZE		MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE		MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2		MOISTURE	
CONSISTENCY / DENSITY		MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS				

Photo

FROM (m):	TO (m):			
TERTIARY COMPONENT		SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT			PLASTICITY
PARTICLE SIZE		MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE		MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2		MOISTURE	
CONSISTENCY / DENSITY		MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS				

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1083 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 1.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & Boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Med sand	to	Coarse sand
Fine gravel	to	Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-rounded	to	Sub-angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders up to 600mm in size

Rootlets to 400mm

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1084 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.3 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 1.5

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & Boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Med sand	to	Coarse sand
Fine gravel	to	Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-rounded	to	Sub-angular

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders up to 600mm in size

Rootlets to 500mm

FROM (m): **TO (m):**

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

FROM (m): **TO (m):**

Photo

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1085 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: Middle of Whataroa Terraces, Farmland, overcast day, slight drizzle

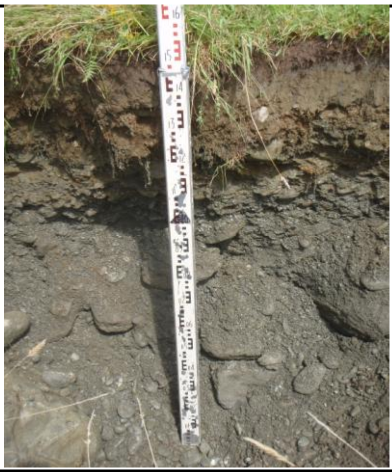
TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.2

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Silt
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 400mm

Photo



FROM (m): 0.2 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Boulders & cobbles
PLASTICITY	non
PARTICLE SIZE	Med sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub angular
MODIFIER	to
PARTICLE SHAPE	Sub rounded
COLOUR 1	grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders up to 800mm in size.

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1086 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.3

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Silt
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 400mm

Photo

FROM (m): 0.3 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Boulders & cobbles
PLASTICITY	non
PARTICLE SIZE	Med sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub angular
MODIFIER	to
PARTICLE SHAPE	Sub rounded
COLOUR 1	grey
COLOUR 2	
MOISTURE	Moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders up to 600mm in size.

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1087 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.6

FROM (m): 0	**TO (m):** 1.6		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Cobbles & boulders	PLASTICITY: non	
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel	
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded	
COLOUR 1: Brownish Grey	COLOUR 2: grading to grey	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Rootlets to 600mm Boulders to 500mm in size Topsoil grading to gravel over 400mm			

FROM (m):	**TO (m):**		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

FROM (m):	**TO (m):**		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1088 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0	**TO (m):** 0.6		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Cobbles	PLASTICITY: non	
PARTICLE SIZE: Medium sand / Fine gravel	MODIFIER: to / to	PARTICLE SIZE: Coarse sand / Coarse gravel	
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded	
COLOUR 1: Brownish Grey	COLOUR 2: grading to grey	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Rootlets to 400mm Stratified gravel zone Topsoil grading to gravel over 200mm			

FROM (m): 0.6	**TO (m):** 1.6		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Cobbles & boulders	PLASTICITY: non	
PARTICLE SIZE: Medium sand / Fine gravel	MODIFIER: to / to	PARTICLE SIZE: Coarse sand / Coarse gravel	
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded	
COLOUR 1: Grey	COLOUR 2	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Boulders up to 700mm in size			

FROM (m):	**TO (m):**		**Photo**
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1089 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand
Fine gravel	to	Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-angular	to	Sub-rounded

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Rootlets to 400mm Boulders to 400mm in size

Topsoil grading to gravel over 300mm

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1090 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.6

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 700mm Topsoil grading to sand over 200mm

Photo

FROM (m): 0.6 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Cobbles & boulders
PLASTICITY	non
PARTICLE SIZE	Medium sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub-angular
MODIFIER	to
PARTICLE SHAPE	Sub-rounded
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders to 400mm in size

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1091 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.8

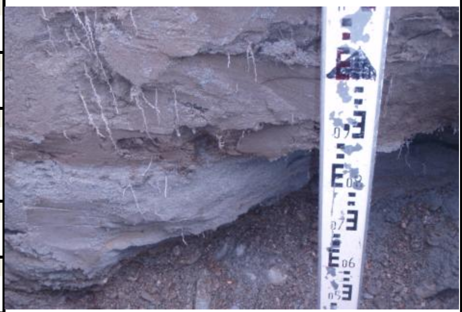
Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	to
PARTICLE SIZE	Medium sand
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 1m Little to no topsoil

Photo

FROM (m): 0.8 **TO (m):** 1.4

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	to
PARTICLE SIZE	Medium sand
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo



FROM (m): 1.4 **TO (m):** 1.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Cobbles & boulders
PLASTICITY	non
PARTICLE SIZE	Coarse sand Fine gravel
MODIFIER	to
PARTICLE SIZE	Coarse gravel
PARTICLE SHAPE	Sub-rounded
MODIFIER	to
PARTICLE SHAPE	Angular
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	1420 gravel?, iron staining, high content of quartz clasts.

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1092 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.8

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Fine sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE
Grey with some	greyish brown	moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Topsoil grading to sand over 200mm

Photo

FROM (m): 0.8 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand Fine gravel	to to	Coarse sand Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-angular	to	Sub-rounded

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Boulders to 800mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1093 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.3

FROM (m): 0 **TO (m):** 0.8

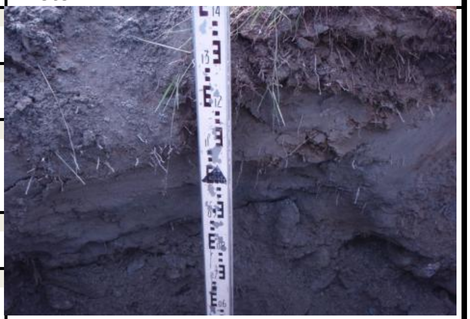
Field	Value	Field	Value	Field	Value
TERTIARY COMPONENT		SECONDARY COMPONENT		PRIMARY COMPONENT	Sand
MODIFIER		MINOR COMPONENT		PLASTICITY	non
PARTICLE SIZE	Fine sand	MODIFIER		PARTICLE SIZE	
PARTICLE SHAPE		MODIFIER		PARTICLE SHAPE	
COLOUR 1	Grey with some	COLOUR 2	greyish brown	MOISTURE	moist
CONSISTENCY / DENSITY	loose	MODIFIER		CONSISTENCY / DENSITY	

ADDITIONAL COMMENTS

Rootlets to 600mm

Topsoil grading to sand over 200mm

Photo



FROM (m): 0.8 **TO (m):** 1.5

Field	Value	Field	Value	Field	Value
TERTIARY COMPONENT		SECONDARY COMPONENT	Sandy	PRIMARY COMPONENT	Gravel
MODIFIER	with	MINOR COMPONENT	Cobbles & boulders	PLASTICITY	non
PARTICLE SIZE	Medium sand Fine gravel	MODIFIER	to to	PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub-angular	MODIFIER	to	PARTICLE SHAPE	Sub-rounded
COLOUR 1	Grey	COLOUR 2		MOISTURE	moist
CONSISTENCY / DENSITY	loose	MODIFIER		CONSISTENCY / DENSITY	

ADDITIONAL COMMENTS

Boulders to 800mm in size

Photo

FROM (m): **TO (m):**

Field	Value	Field	Value	Field	Value
TERTIARY COMPONENT		SECONDARY COMPONENT		PRIMARY COMPONENT	
MODIFIER		MINOR COMPONENT		PLASTICITY	
PARTICLE SIZE		MODIFIER		PARTICLE SIZE	
PARTICLE SHAPE		MODIFIER		PARTICLE SHAPE	
COLOUR 1		COLOUR 2		MOISTURE	
CONSISTENCY / DENSITY		MODIFIER		CONSISTENCY / DENSITY	

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1094 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.4

FROM (m): 0 **TO (m):** 0.6

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Grey with some
COLOUR 2	greyish brown
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Rootlets to 700mm Topsoil grading to sand over 200mm

Photo

FROM (m): 0.6 **TO (m):** 1.4

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Cobbles & boulders
PLASTICITY	non
PARTICLE SIZE	Medium sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub-angular
MODIFIER	to
PARTICLE SHAPE	Sub-rounded
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders to 700mm in size

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1095 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.6

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT: Sand
MODIFIER	MINOR COMPONENT	PLASTICITY: non
PARTICLE SIZE: Fine sand	MODIFIER	PARTICLE SIZE
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
COLOUR 1: Grey with some	COLOUR 2: greyish brown	MOISTURE: moist
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Topsoil grading to sand over 200mm

Photo

FROM (m): 0.6 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel
MODIFIER: with	MINOR COMPONENT: Cobbles & boulders	PLASTICITY: non
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded
COLOUR 1: Grey	COLOUR 2	MOISTURE: moist
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Boulders to 600mm in size

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
MODIFIER	MINOR COMPONENT	PLASTICITY
PARTICLE SIZE	MODIFIER	PARTICLE SIZE
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
COLOUR 1	COLOUR 2	MOISTURE
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1096 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.2

FROM (m): 0 **TO (m):** 0.5

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

FROM (m): 0.5 **TO (m):** 1.2

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Cobbles & boulders
PLASTICITY	non
PARTICLE SIZE	Medium sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub-angular
MODIFIER	to
PARTICLE SHAPE	Sub-rounded
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders to 800mm in size

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1097 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 0.9

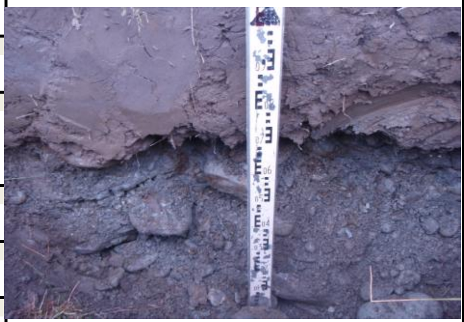
Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

FROM (m): 0.9 **TO (m):** 1.6

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	Sandy
PRIMARY COMPONENT	Gravel
MODIFIER	with
MINOR COMPONENT	Cobbles & boulders
PLASTICITY	non
PARTICLE SIZE	Medium sand Fine gravel
MODIFIER	to to
PARTICLE SIZE	Coarse sand Coarse gravel
PARTICLE SHAPE	Sub-angular
MODIFIER	to
PARTICLE SHAPE	Sub-rounded
COLOUR 1	Grey
COLOUR 2	
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Boulders to 800mm in size

Photo



FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1098 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0	TO (m): 1.2		Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT: Sand	
MODIFIER	MINOR COMPONENT	PLASTICITY: non	
PARTICLE SIZE: Fine sand	MODIFIER: to	PARTICLE SIZE: medium sand	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1: Brownish	COLOUR 2: Grey	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Topsoil grades over 200mm			

FROM (m): 1.2	TO (m): 1.5		Photo
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel	
MODIFIER: with	MINOR COMPONENT: Cobbles & boulders	PLASTICITY: non	
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel	
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded	
COLOUR 1: Grey	COLOUR 2	MOISTURE: moist	
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS: Boulders to 400mm in size			

FROM (m):	TO (m):		Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT	
MODIFIER	MINOR COMPONENT	PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE	
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE	
COLOUR 1	COLOUR 2	MOISTURE	
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS			

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1099 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.6

FROM (m): 0 **TO (m):** 1.6

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	Sand
MODIFIER	
MINOR COMPONENT	
PLASTICITY	non
PARTICLE SIZE	Fine sand
MODIFIER	to
PARTICLE SIZE	medium sand
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	Brownish
COLOUR 2	Grey
MOISTURE	moist
CONSISTENCY / DENSITY	loose
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	Topsoil grades over 200mm

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

FROM (m): **TO (m):**

Field	Value
TERTIARY COMPONENT	
SECONDARY COMPONENT	
PRIMARY COMPONENT	
MODIFIER	
MINOR COMPONENT	
PLASTICITY	
PARTICLE SIZE	
MODIFIER	
PARTICLE SIZE	
PARTICLE SHAPE	
MODIFIER	
PARTICLE SHAPE	
COLOUR 1	
COLOUR 2	
MOISTURE	
CONSISTENCY / DENSITY	
MODIFIER	
CONSISTENCY / DENSITY	
ADDITIONAL COMMENTS	

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1100 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

FROM (m): 0.2 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand	to	Coarse sand
Fine gravel	to	Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-angular	to	Sub-rounded

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Rootlets to 600mm Boulders to 600mm in size

Topsoil grading to gravel over 300mm

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

DATE: 27 / 01 / 2011 **TEST PIT:** 1101 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.1 **REMARKS:**

EOH (m): 1.5

FROM (m): 0 **TO (m):** 0.2

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
		Sand

MODIFIER	MINOR COMPONENT	PLASTICITY
		non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
fine sand		

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE
grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Photo

FROM (m): 0.2 **TO (m):** 1.5

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT
	Sandy	Gravel

MODIFIER	MINOR COMPONENT	PLASTICITY
with	Cobbles & boulders	non

PARTICLE SIZE	MODIFIER	PARTICLE SIZE
Medium sand Fine gravel	to to	Coarse sand Coarse gravel

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE
Sub-angular	to	Sub-rounded

COLOUR 1	COLOUR 2	MOISTURE
Grey		moist

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY
loose		

ADDITIONAL COMMENTS

Small lense of brown coarse sand at the top of unit, buried soil horizon?

Photo

FROM (m): **TO (m):**

TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT

MODIFIER	MINOR COMPONENT	PLASTICITY

PARTICLE SIZE	MODIFIER	PARTICLE SIZE

PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE

COLOUR 1	COLOUR 2	MOISTURE

CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY

ADDITIONAL COMMENTS

Photo

SUMMARY TEST PIT LOG - WHATAROA DFDP SITE

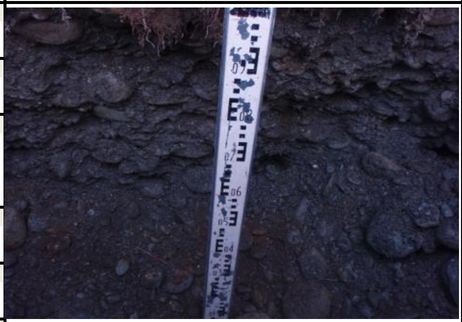
DATE: 27 / 01 / 2011 **TEST PIT:** 1102 **LOGGED BY:** Andrew Klahn

SITE DESCRIPTION: South of Whataroa Terraces, 1620 degradation surface, Farmland, overcast day, slight drizzle

TOPSOIL (m): 0.2 **REMARKS:**

EOH (m): 1.5

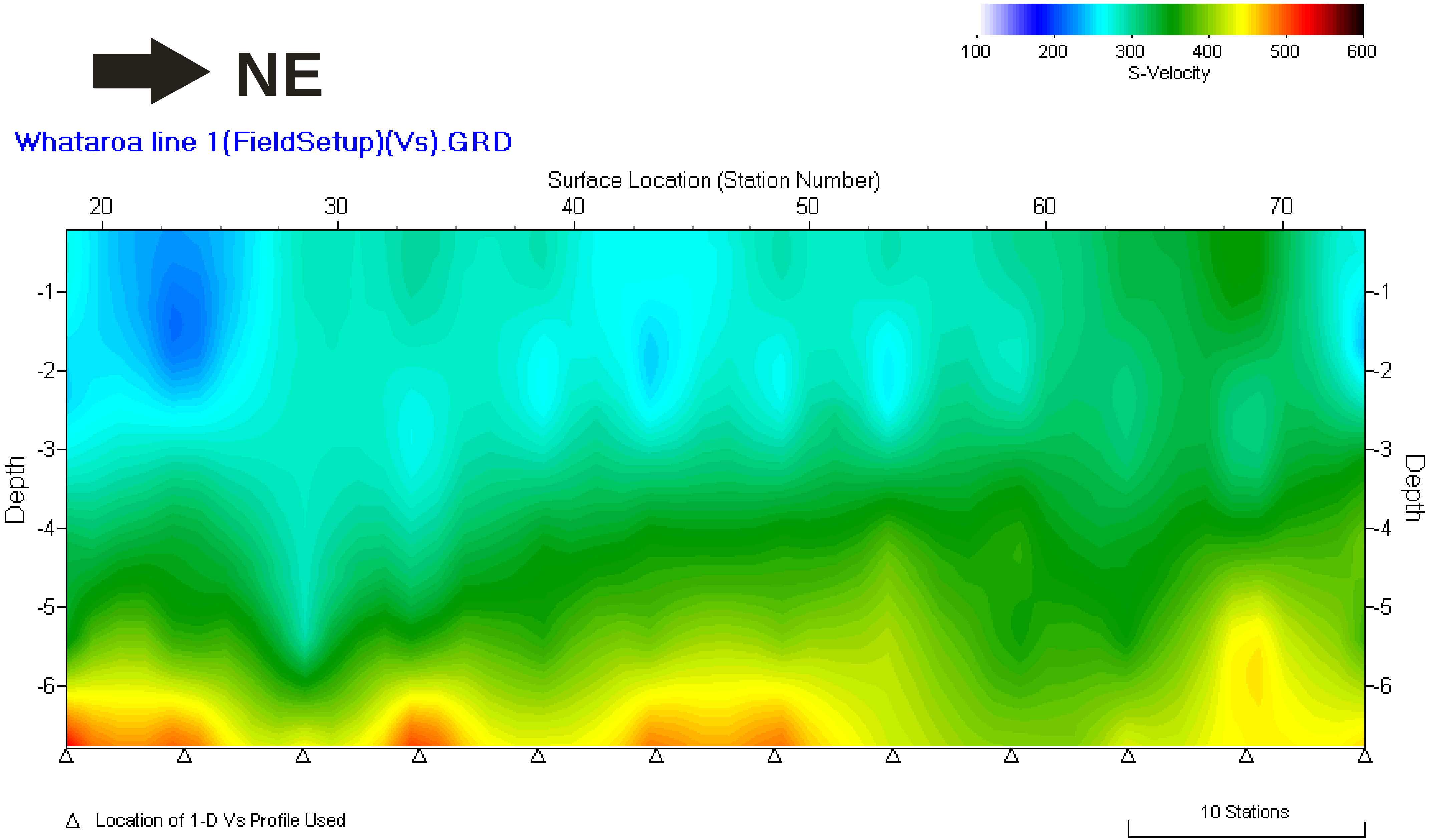
FROM (m): 0	TO (m): 0.4			Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT: Sand		
MODIFIER	MINOR COMPONENT		PLASTICITY: non	
PARTICLE SIZE: Fine sand	MODIFIER	PARTICLE SIZE		
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE		
COLOUR 1: Brownish	COLOUR 2: Grey	MOISTURE: moist		
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY		
ADDITIONAL COMMENTS				

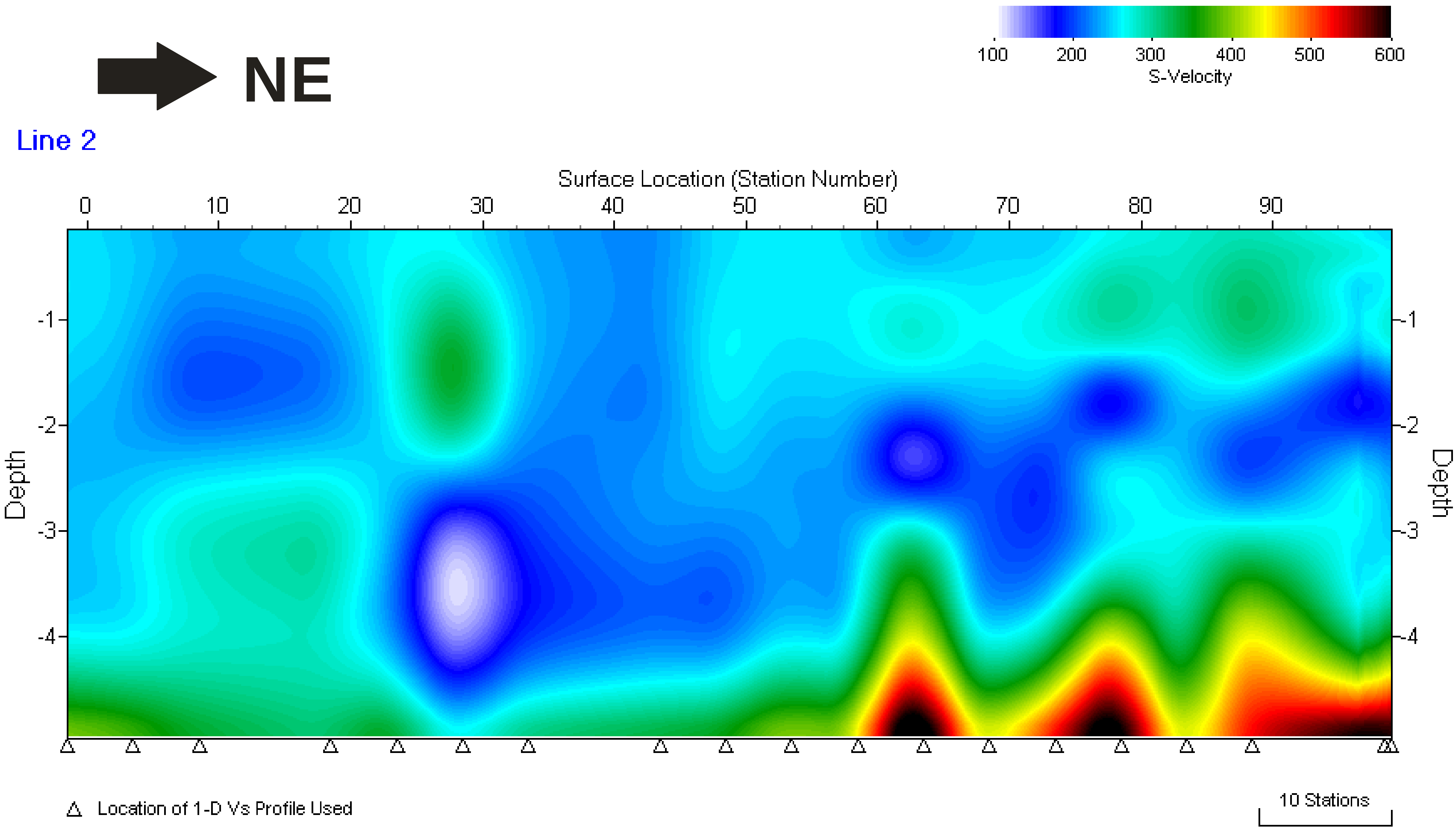
FROM (m): 0.4	TO (m): 1.5			Photo
TERTIARY COMPONENT	SECONDARY COMPONENT: Sandy	PRIMARY COMPONENT: Gravel		
MODIFIER: with	MINOR COMPONENT: Cobbles & boulders		PLASTICITY: non	
PARTICLE SIZE: Medium sand Fine gravel	MODIFIER: to to	PARTICLE SIZE: Coarse sand Coarse gravel		
PARTICLE SHAPE: Sub-angular	MODIFIER: to	PARTICLE SHAPE: Sub-rounded		
COLOUR 1: Grey	COLOUR 2	MOISTURE: moist		
CONSISTENCY / DENSITY: loose	MODIFIER	CONSISTENCY / DENSITY		
ADDITIONAL COMMENTS: Boulders to 300mm in size				

FROM (m):	TO (m):			Photo
TERTIARY COMPONENT	SECONDARY COMPONENT	PRIMARY COMPONENT		
MODIFIER	MINOR COMPONENT		PLASTICITY	
PARTICLE SIZE	MODIFIER	PARTICLE SIZE		
PARTICLE SHAPE	MODIFIER	PARTICLE SHAPE		
COLOUR 1	COLOUR 2	MOISTURE		
CONSISTENCY / DENSITY	MODIFIER	CONSISTENCY / DENSITY		
ADDITIONAL COMMENTS				

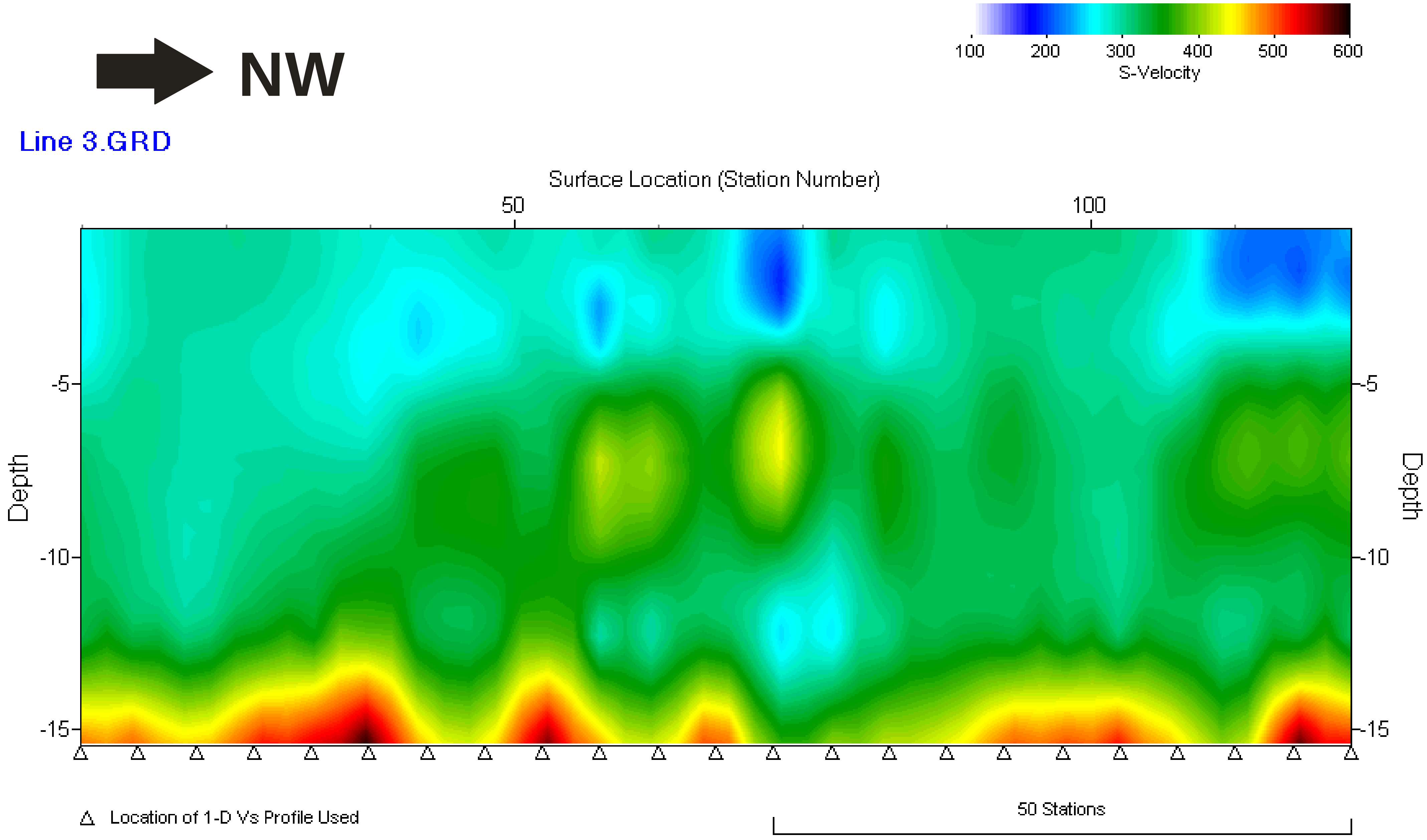
Appendix E – MASW Profiles

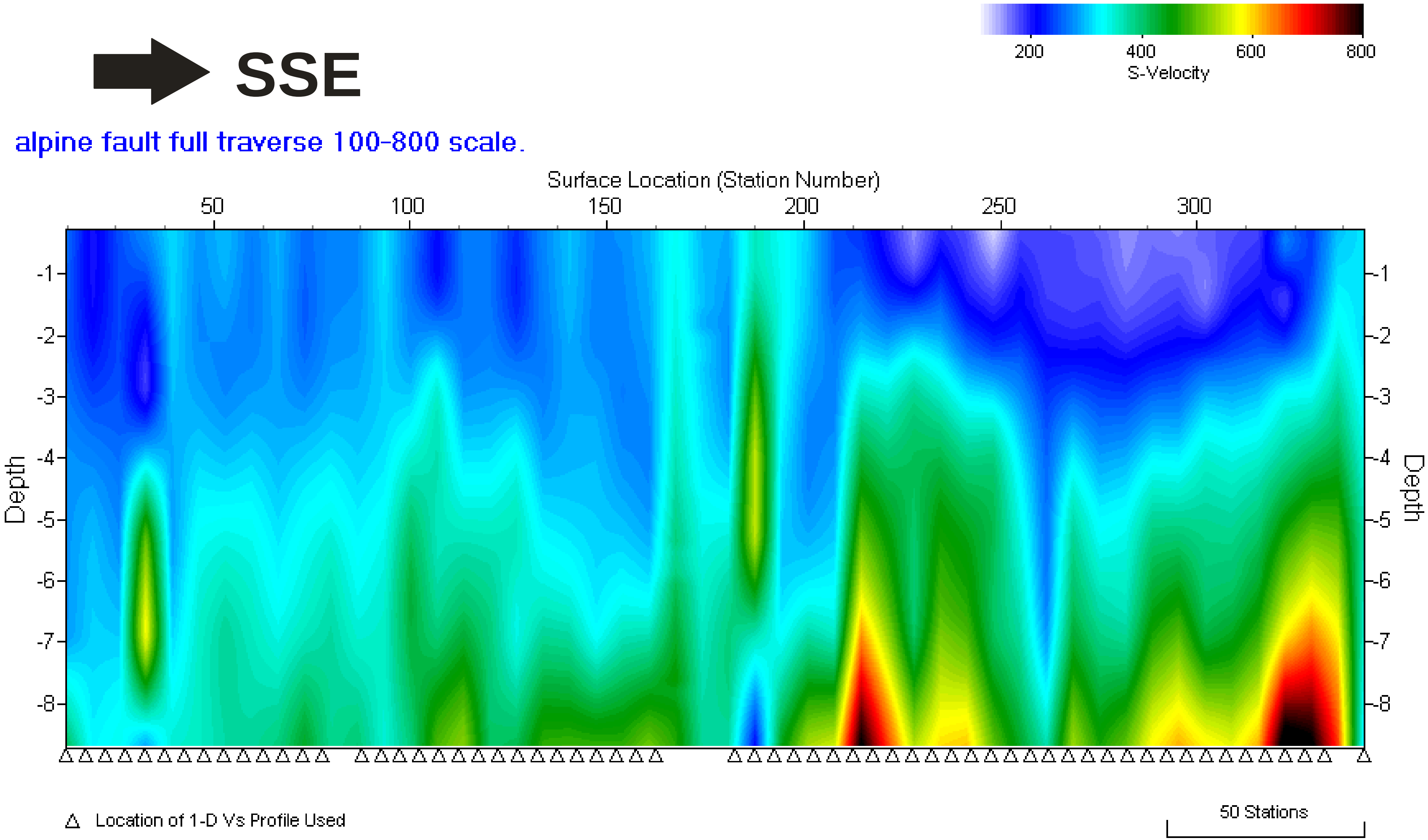
Line	Date	Position	Elevation (m)
Line 1 Start	14/04/2010 10:05	S43.29776 E170.41558	113.079956
Line 1 End	14/04/2010 10:03	S43.29824 E170.41550	111.397705
Line 2 Start	14/04/2010 10:35	S43.29828 E170.41545	110.196044
Line 2 End	14/04/2010 12:12	S43.29905 E170.41484	106.350708
Line 3 Start	14/04/2010 13:46	S43.29824 E170.41361	108.273437
Line 3 Mid	14/04/2010 16:27	S43.29787 E170.41325	105.389404
Line 3 End	14/04/2010 14:49	S43.29742 E170.41289	108.273437
AF pt1 Start	15/04/2010 9:14	S43.28263 E170.39715	93.853759
AF pt1 End	15/04/2010 10:49	S43.28318 E170.39728	98.419921
AF pt2 Start	15/04/2010 10:49	S43.28318 E170.39728	98.419921
AF pt2 Mid	15/04/2010 12:00	S43.28380 E170.39846	96.016723
AF pt2 End	15/04/2010 13:53	S43.28477 E170.39970	100.582885


NE
100
200
300
400
500
600
S-Velocity
Whataroa line 1(FieldSetup)(Vs).GRD
Surface Location (Station Number)
20
30
40
50
60
70
-1
-2
-3
-4
-5
-6
Depth
Depth
Location of 1-D Vs Profile Used
10 Stations



NE
Line 2
100
200
300
400
500
600
S-Velocity
Surface Location (Station Number)
0
10
20
30
40
50
60
70
80
90
-1
-2
-3
-4
Depth
Depth
Location of 1-D Vs Profile Used
10 Stations

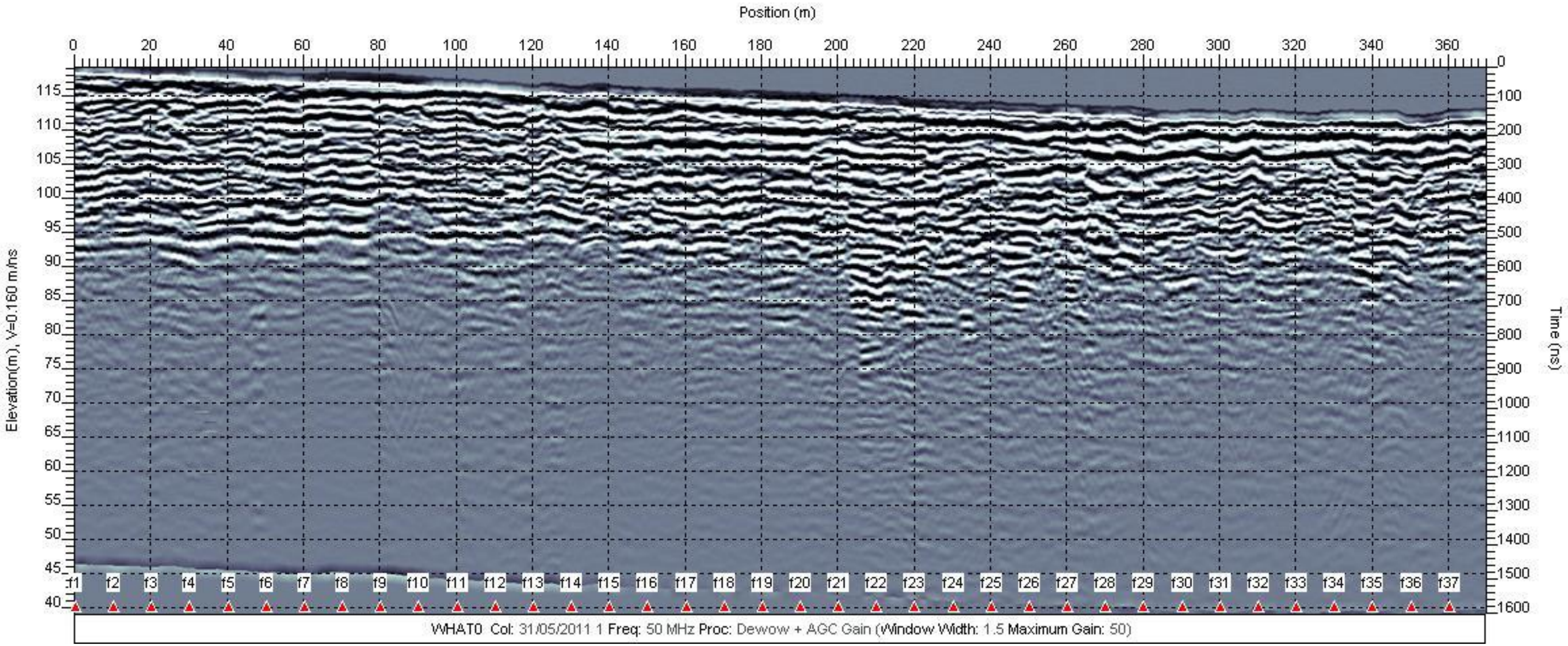

NW
Line 3.GRD
100
200
300
400
500
600
S-Velocity
Surface Location (Station Number)
50
100
Depth
-5
-10
-15
Depth
-5
-10
-15
Location of 1-D Vs Profile Used
50 Stations



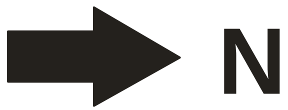
SSE
200
400
600
800
S-Velocity
alpine fault full traverse 100-800 scale.
Surface Location (Station Number)
50
100
150
200
250
300
Depth
-1
-2
-3
-4
-5
-6
-7
-8
Location of 1-D Vs Profile Used
50 Stations

Appendix F – GPR Profiles

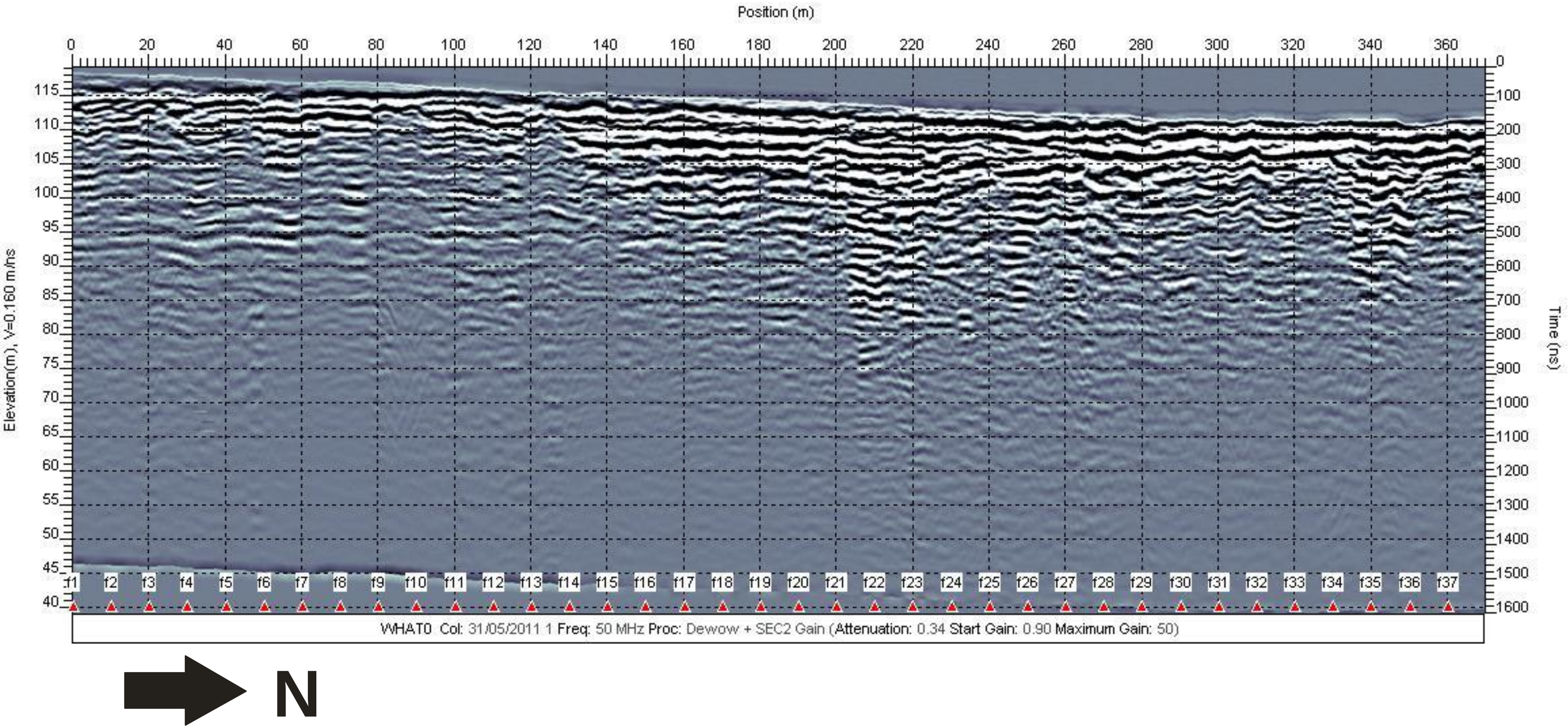
Line	Date	Length	X	Y	Z
What0 Start	31/05/2011	373.151	170.41039959700	-43.30151203360	114.54950674100
What0 End	31/05/2011	373.151	170.41028570900	-43.29820379060	107.38002566700
What1 Start	31/05/2011	89.557	170.40988808600	-43.29634418980	102.31157544900
What1 End	31/05/2011	89.557	170.41010531400	-43.29555710840	100.84526557600
What2 Start	2/06/2011	211.997	170.41008233300	-43.29564105460	100.51909914500
What2 End	2/06/2011	211.997	170.41011709600	-43.29375007240	98.79098172870
What3 Start	31/05/2011	190.014	170.41028563000	-43.29347796000	98.58686002650
What3 End	31/05/2011	190.014	170.41047000000	-43.29178834630	96.32483525980
What4 Start	31/05/2011	203.362	170.40611667900	-43.29001294070	93.93215642740
What4 End	31/05/2011	203.362	170.40641475000	-43.29177884400	95.89985946040
What5 Start	31/05/2011	422.615	170.41227917900	-43.29447400150	99.70374427630
What5 End	31/05/2011	422.615	170.41559849900	-43.29731915470	104.31251294200
What8 Start	2/06/2011	154.090	170.41466708900	-43.29920622880	106.11596965200
What8 End	2/06/2011	154.090	170.41533228200	-43.29795293260	105.70670974800

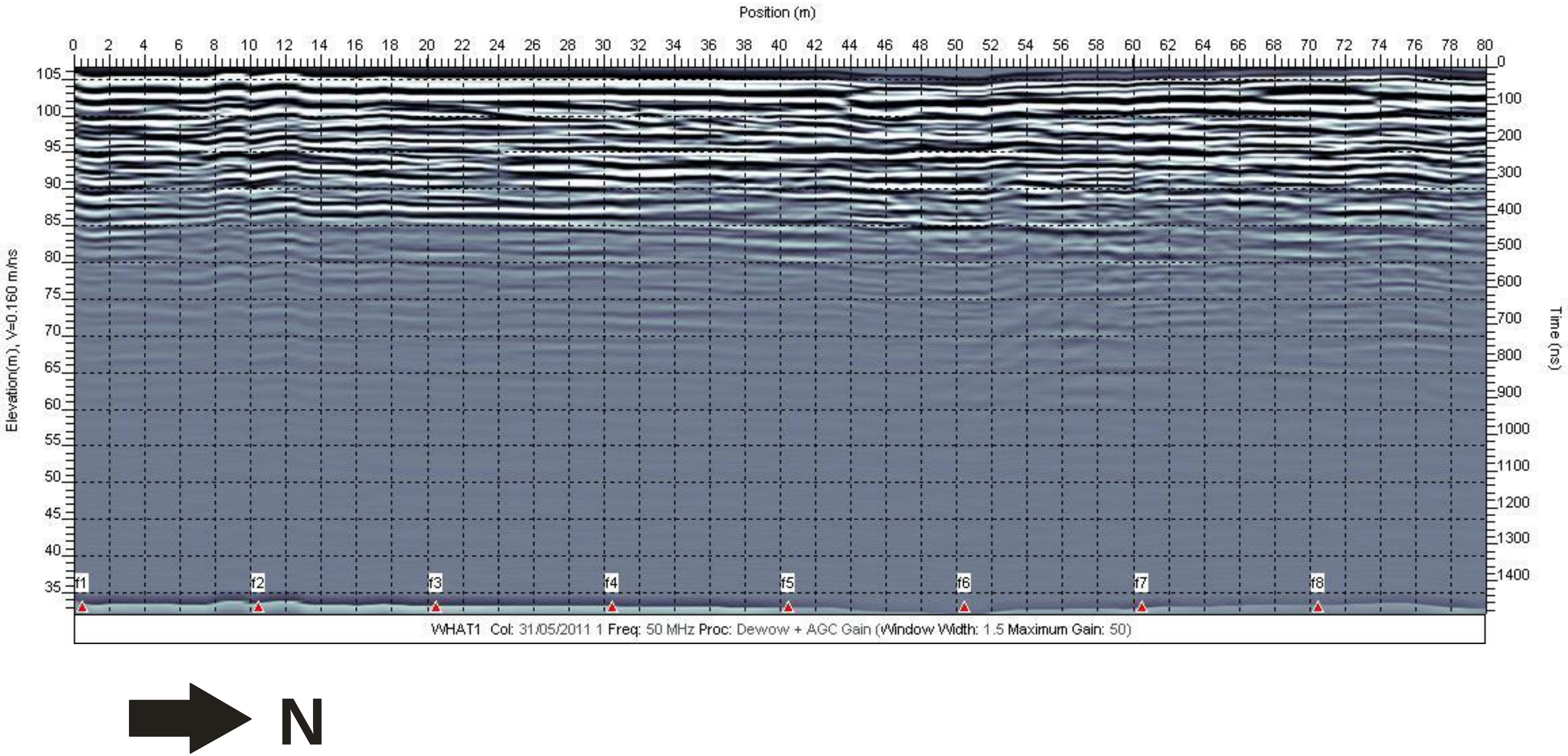


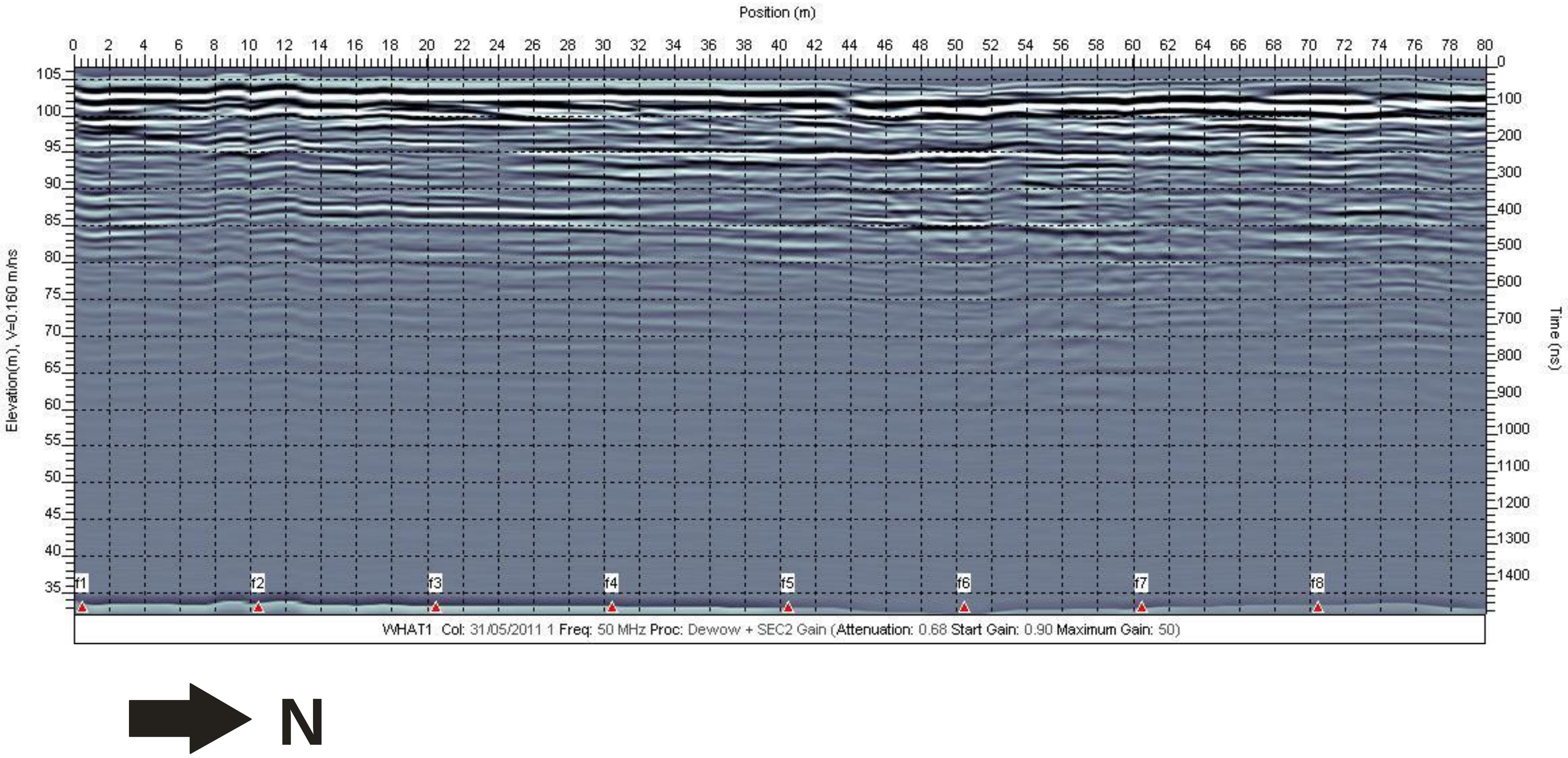
Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
WHAT0 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)

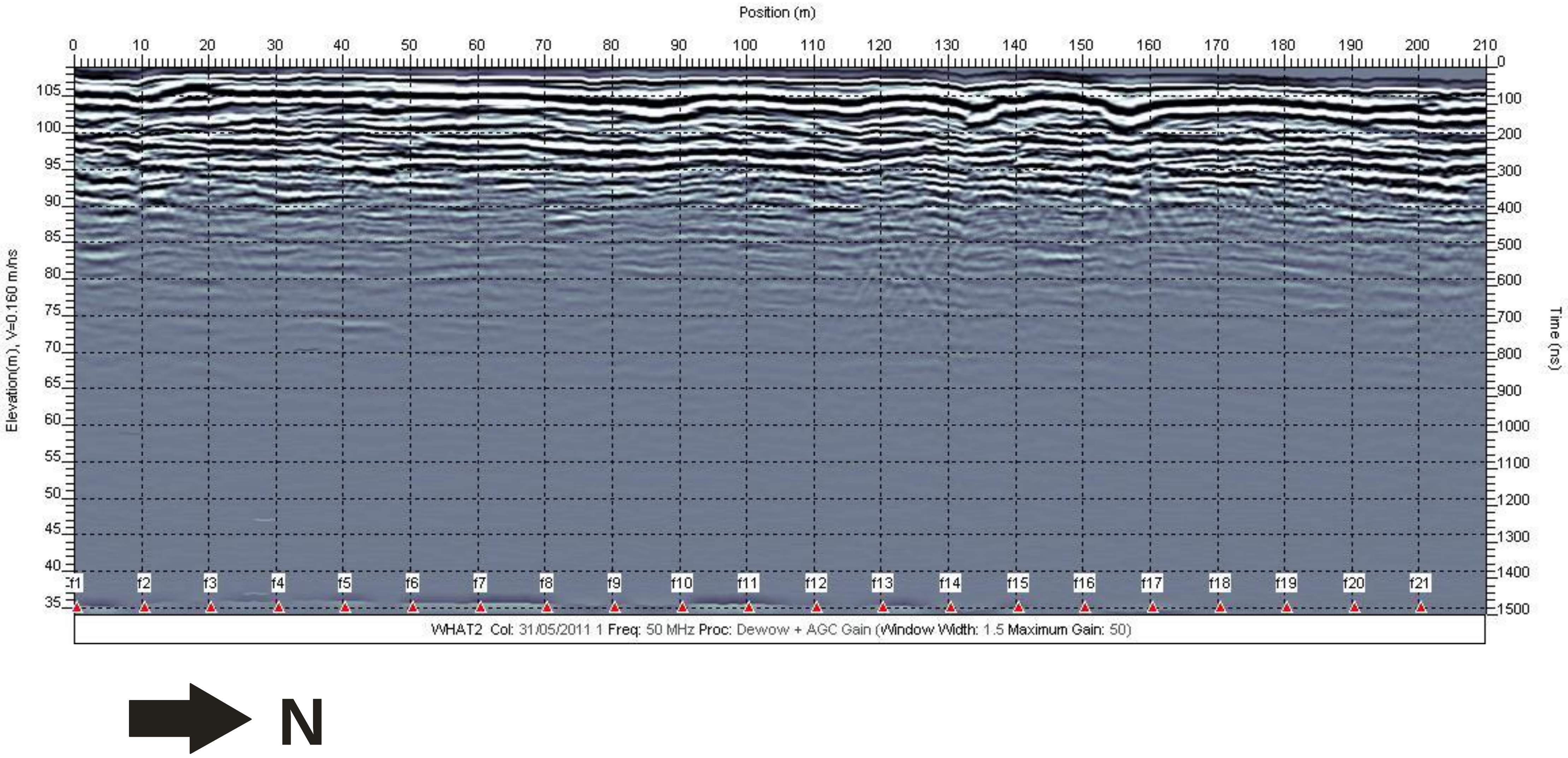


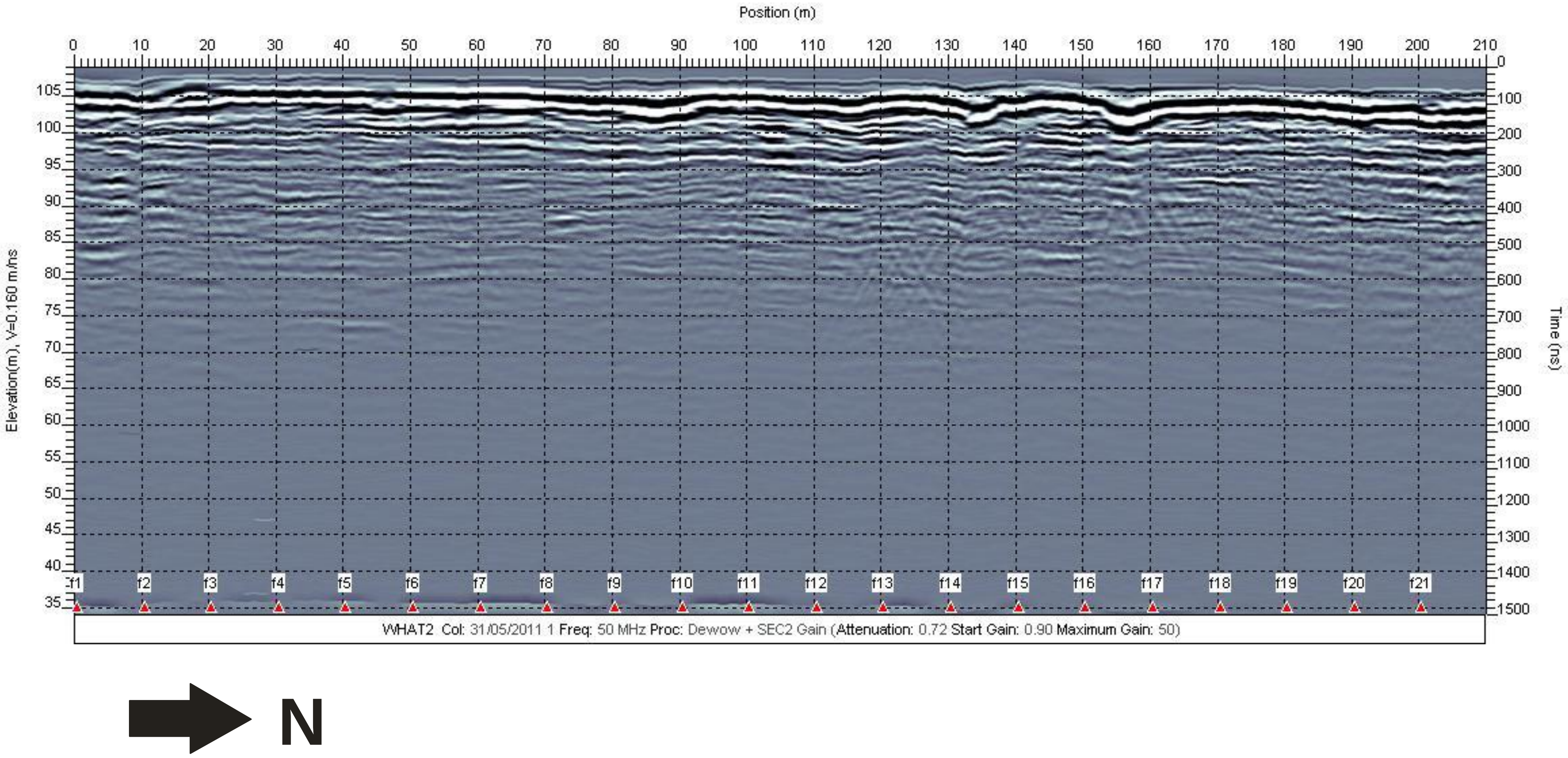
N

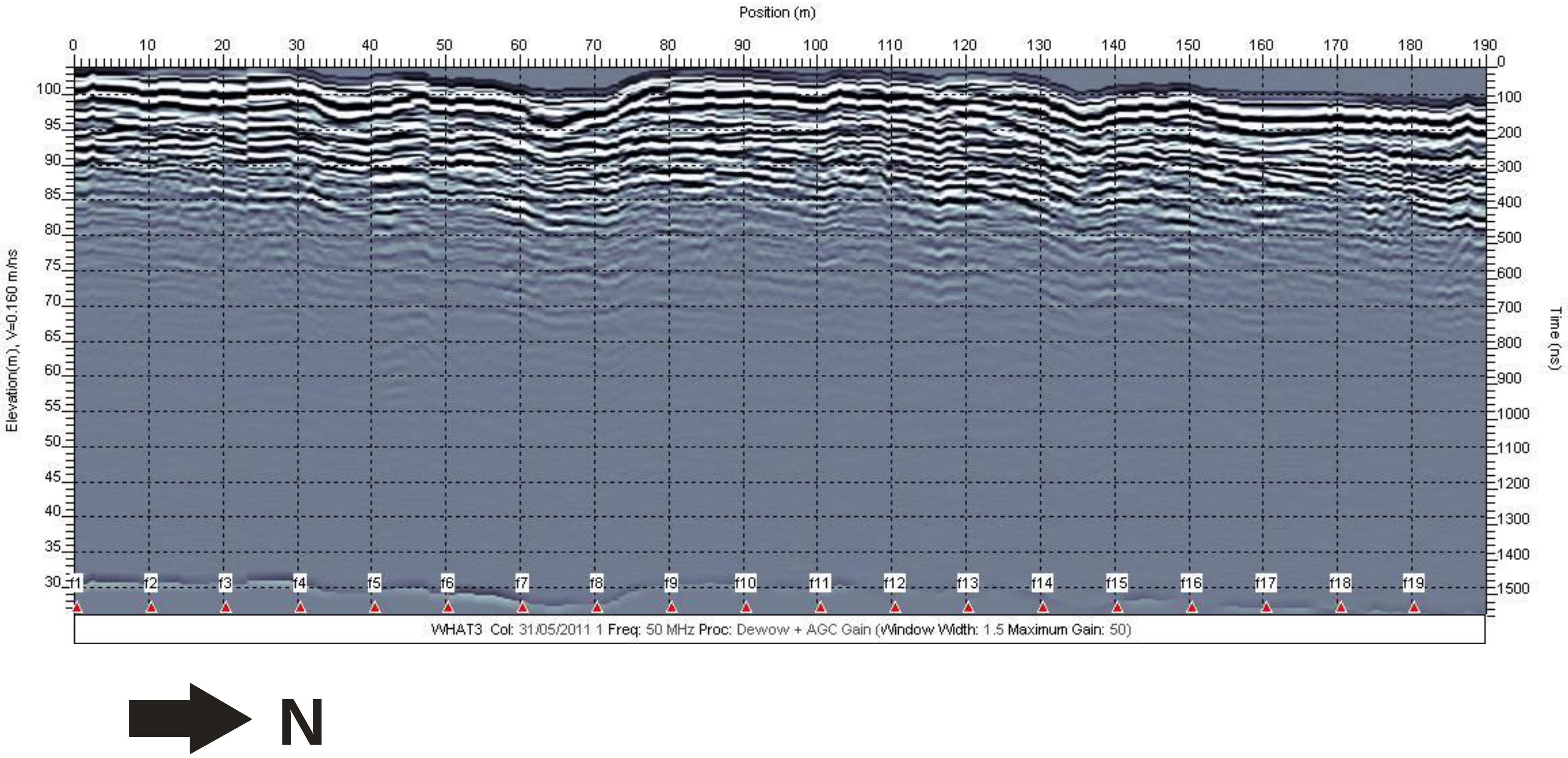

Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
WHAT0 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.34 Start Gain: 0.90 Maximum Gain: 50)
N


Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
WHAT1 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
N

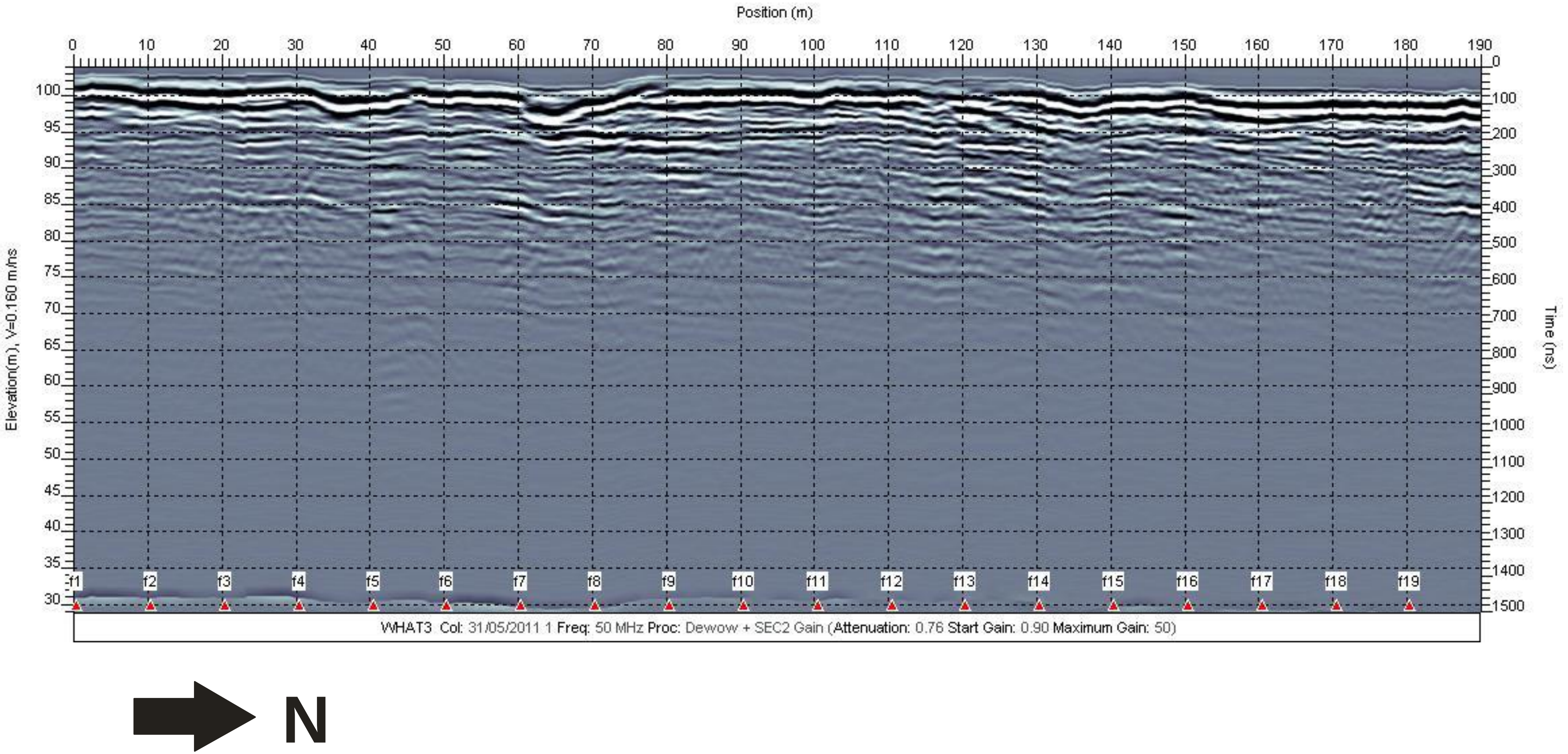

Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
WHAT1 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.68 Start Gain: 0.90 Maximum Gain: 50)
N

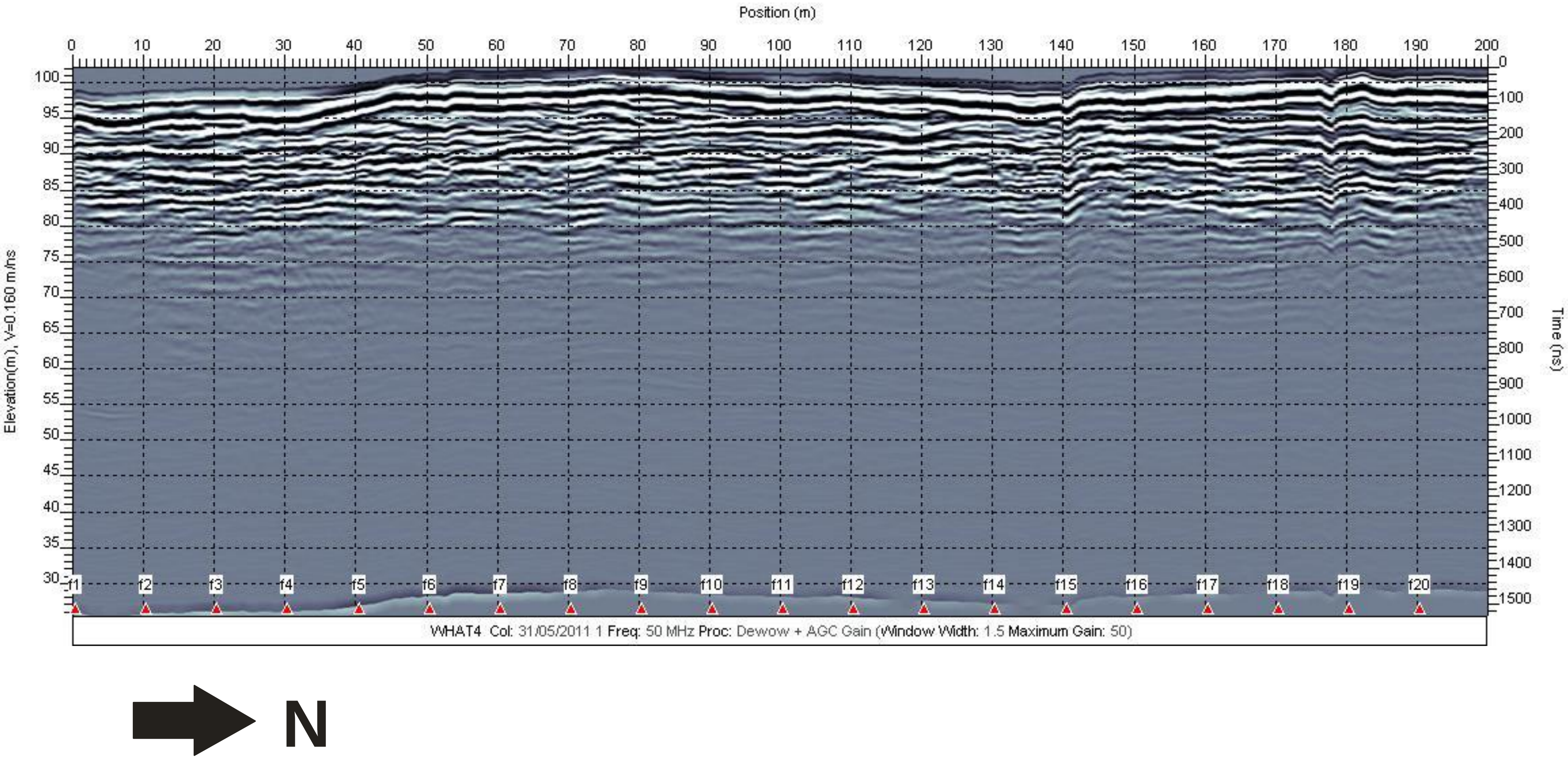

Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 f13 f14 f15 f16 f17 f18 f19 f20 f21
WHAT2 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
N


Position (m)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
Elevation(m), V=0.160 m/ns
105 100 95 90 85 80 75 70 65 60 55 50 45 40 35
Time (ns)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 f13 f14 f15 f16 f17 f18 f19 f20 f21
WHAT2 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.72 Start Gain: 0.90 Maximum Gain: 50)
N

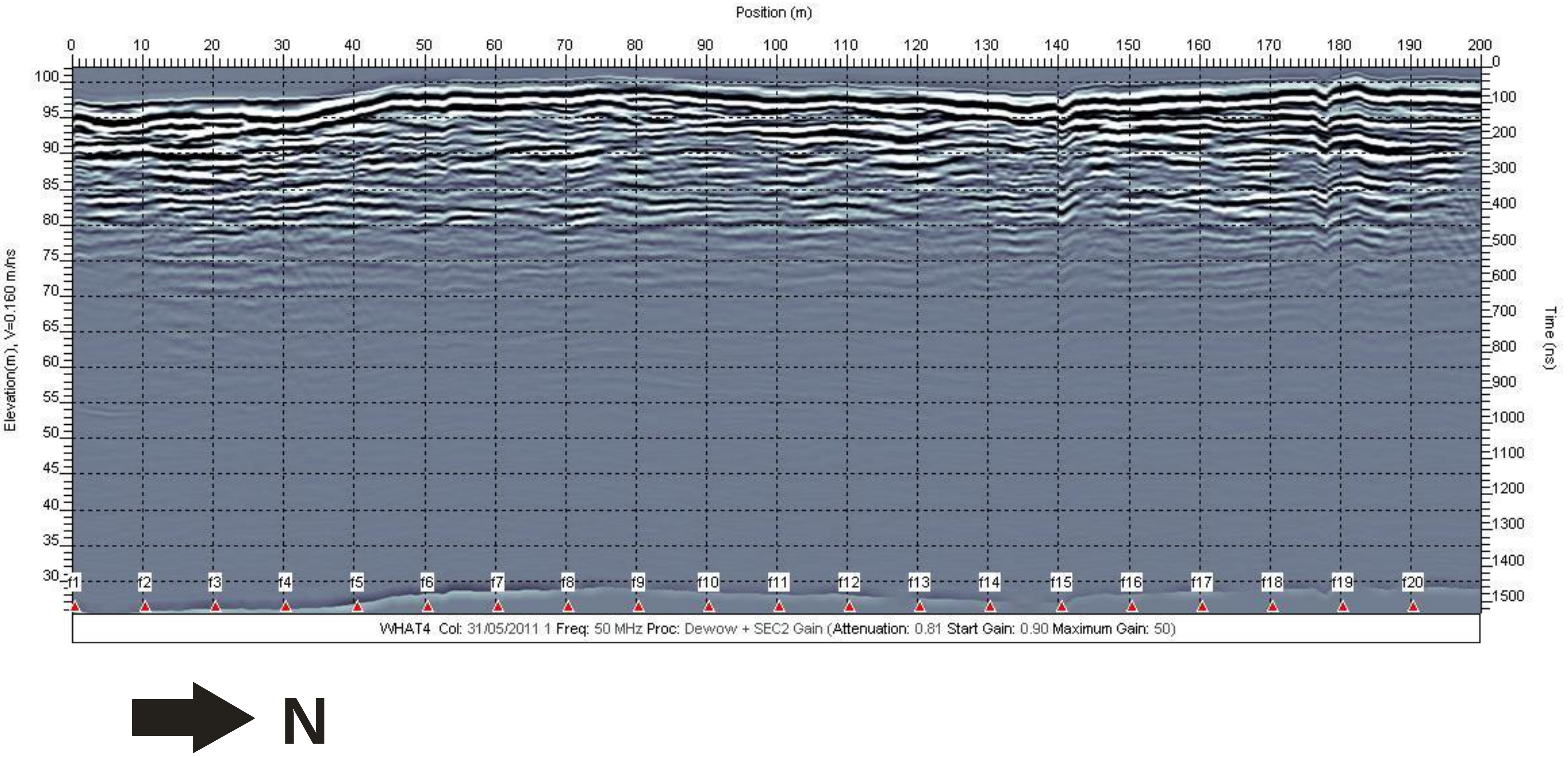


Position (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
Elevation(m), V=0.160 m/ns
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
Time (ns)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
f1
f2
f3
f4
f5
f6
f7
f8
f9
f10
f11
f12
f13
f14
f15
f16
f17
f18
f19
WHAT3 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
N

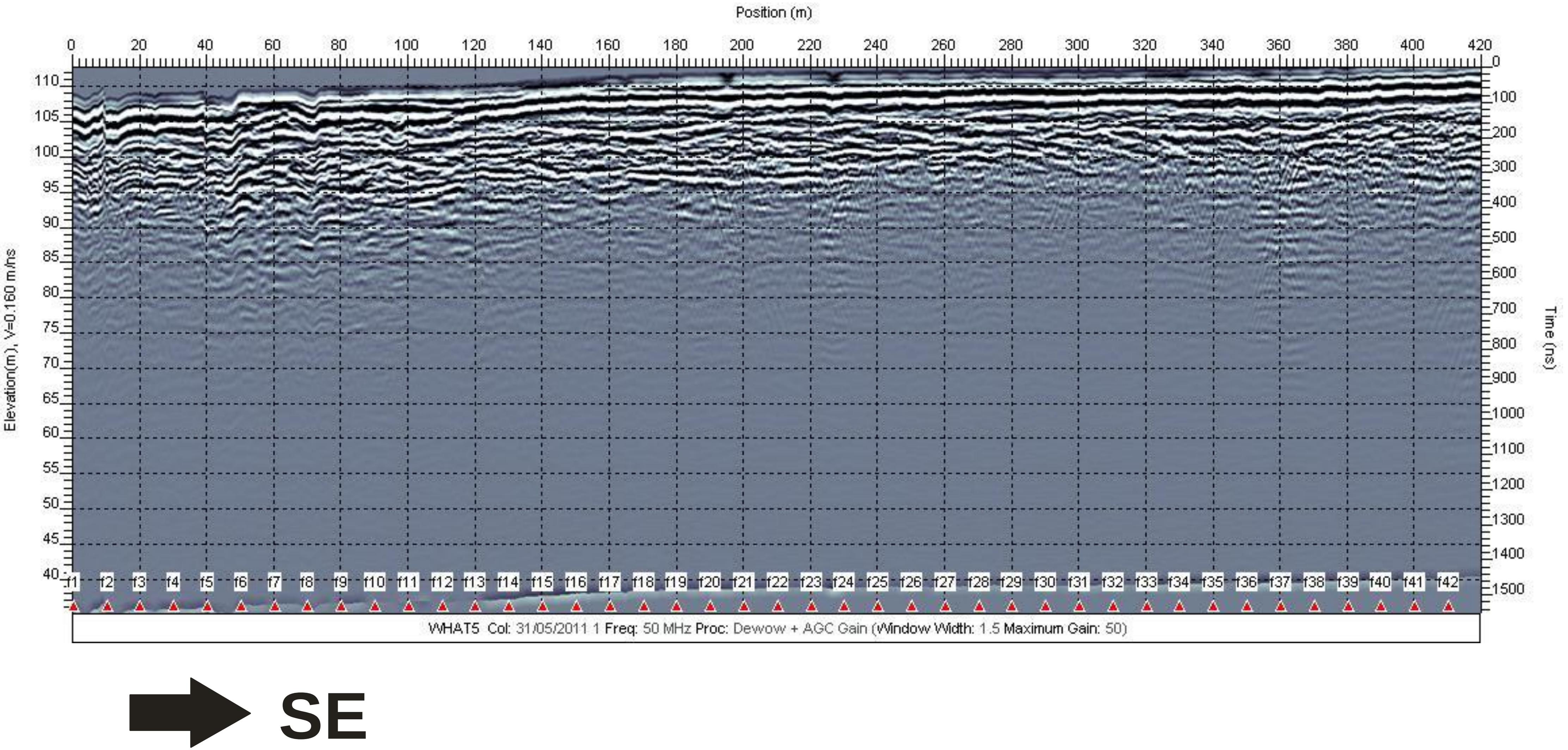

Position (m)
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
Elevation(m), V=0.160 m/ns
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30
Time (ns)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 f13 f14 f15 f16 f17 f18 f19
WHAT3 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.76 Start Gain: 0.90 Maximum Gain: 50)
N

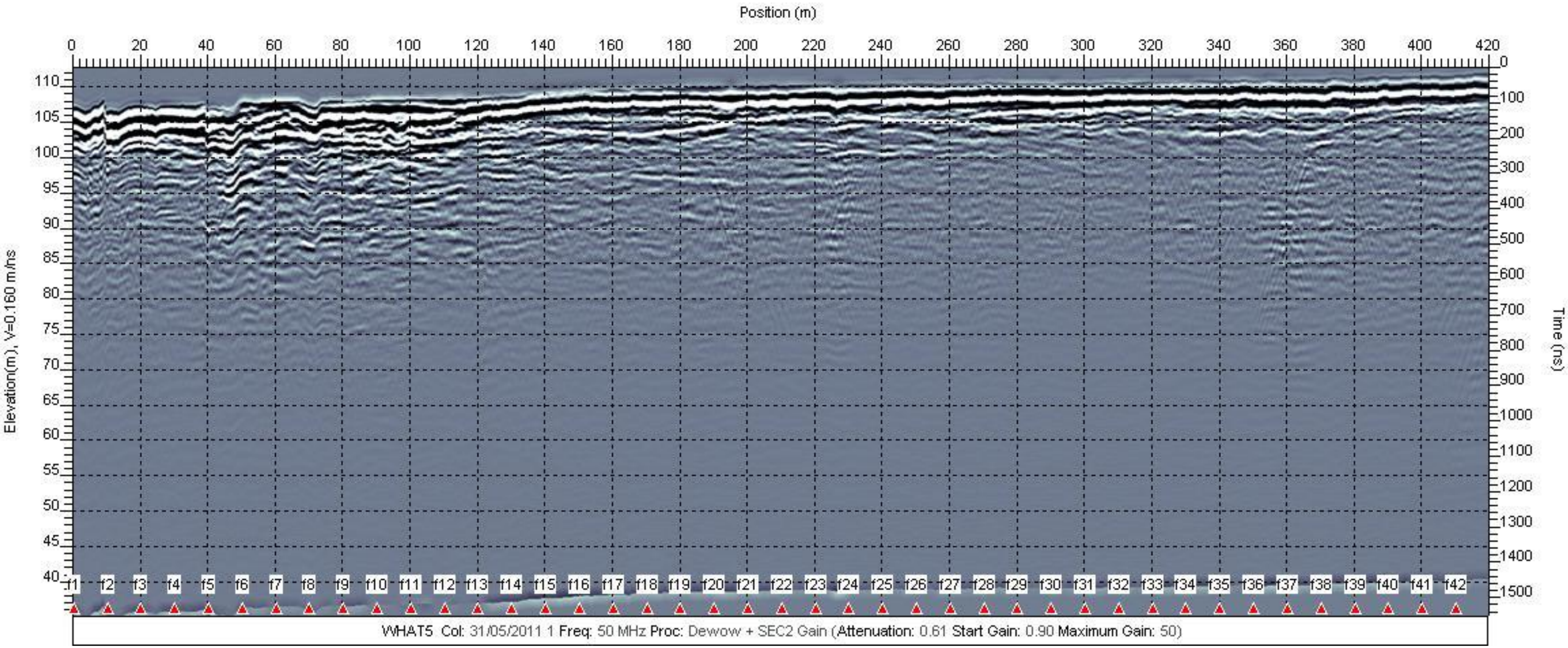


Position (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
f9
f10
f11
f12
f13
f14
f15
f16
f17
f18
f19
f20
WHAT4 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
N

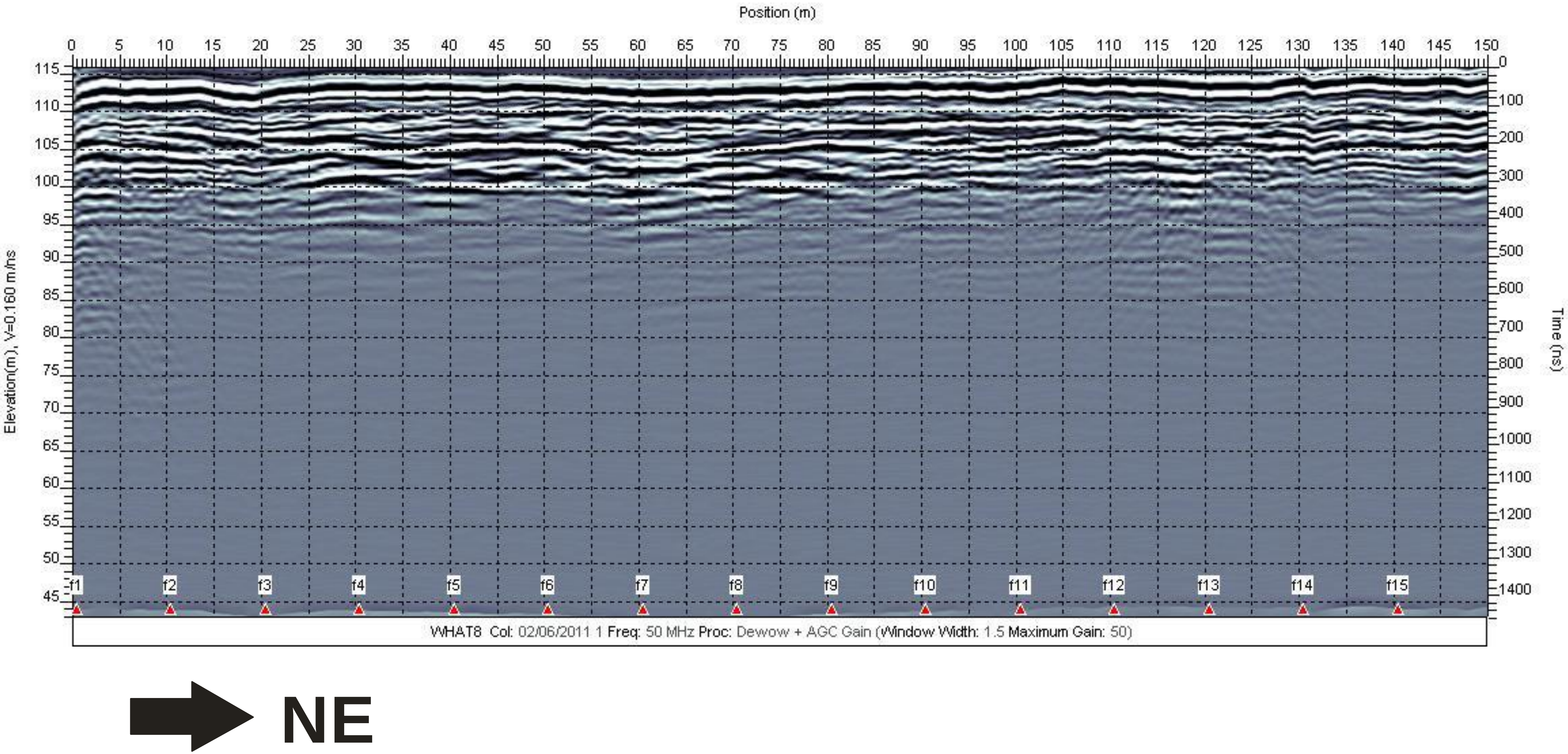


Position (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
f9
f10
f11
f12
f13
f14
f15
f16
f17
f18
f19
f20
WHAT4 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.81 Start Gain: 0.90 Maximum Gain: 50)
N

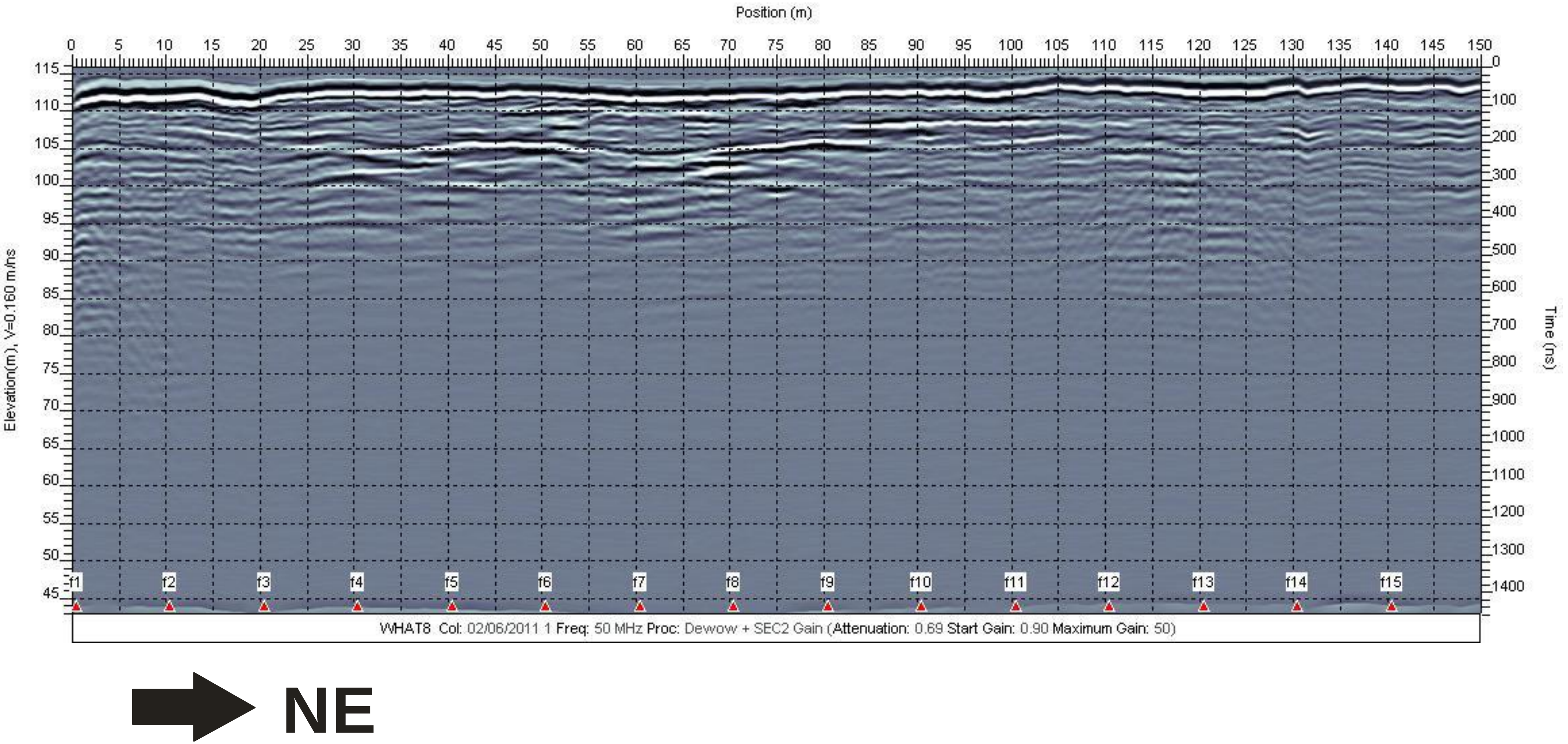

Position (m)
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420
Elevation(m), V=0.160 m/ns
110 105 100 95 90 85 80 75 70 65 60 55 50 45 40
Time (ns)
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500
f1 f2 f3 f4 f5 f6 f7 f8 f9 f10 f11 f12 f13 f14 f15 f16 f17 f18 f19 f20 f21 f22 f23 f24 f25 f26 f27 f28 f29 f30 f31 f32 f33 f34 f35 f36 f37 f38 f39 f40 f41 f42
WHAT5 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
SE


Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
WHAT5 Col: 31/05/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.61 Start Gain: 0.90 Maximum Gain: 50)

SE

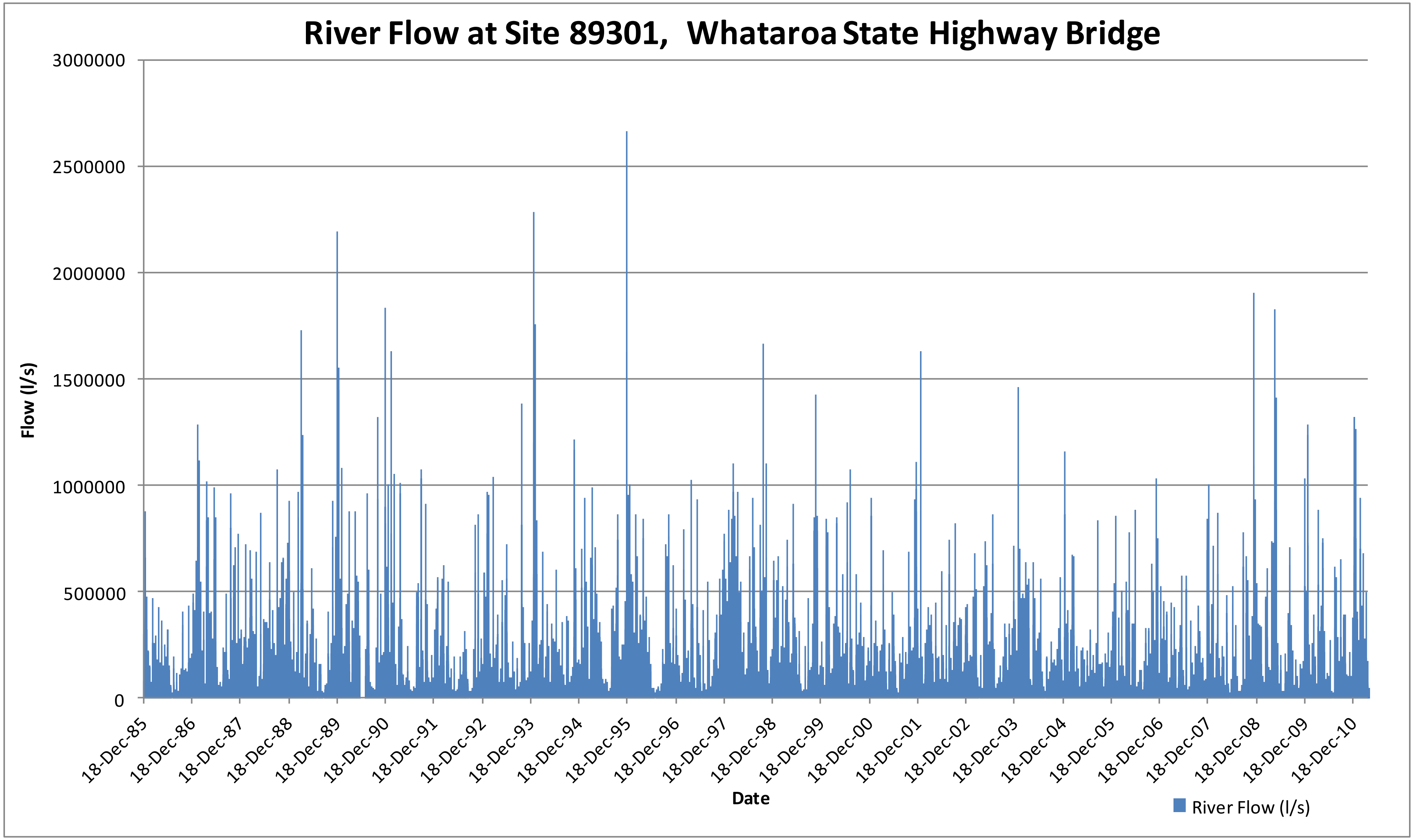


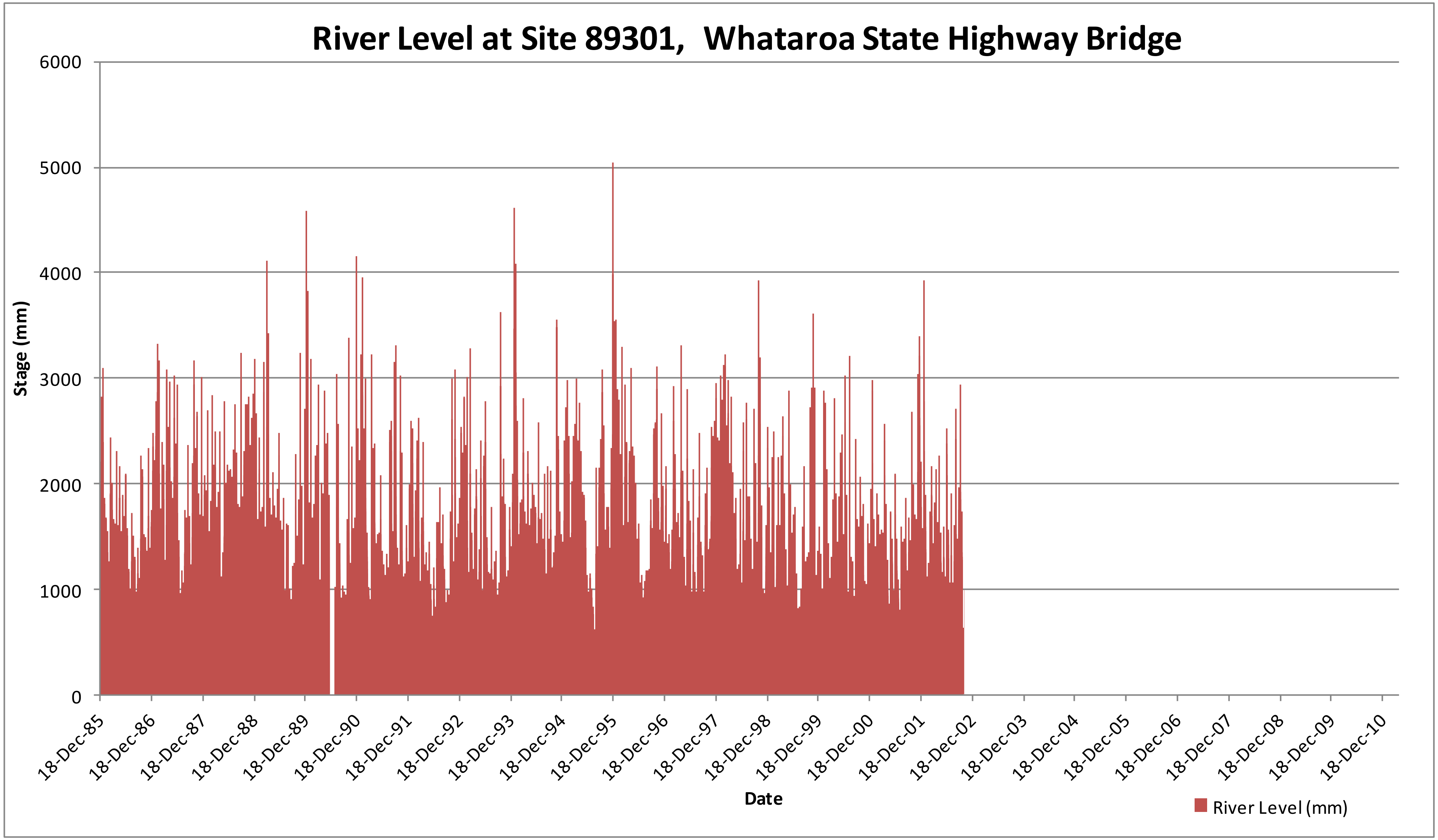
Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
f9
f10
f11
f12
f13
f14
f15
WHAT8 Col: 02/06/2011 1 Freq: 50 MHz Proc: Dewow + AGC Gain (Window Width: 1.5 Maximum Gain: 50)
NE

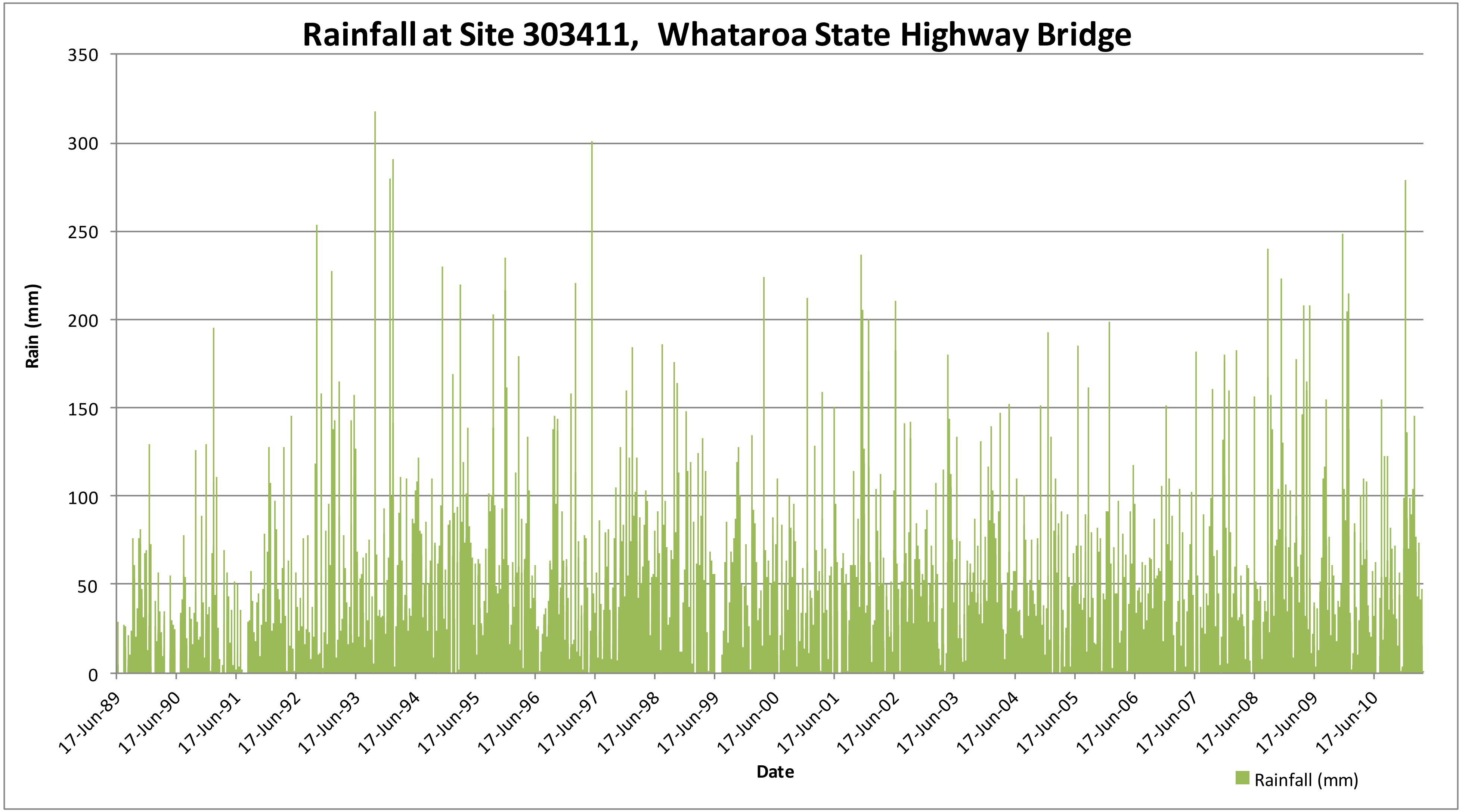


Position (m)
Elevation(m), V=0.160 m/ns
Time (ns)
f1
f2
f3
f4
f5
f6
f7
f8
f9
f10
f11
f12
f13
f14
f15
WHAT8 Col: 02/06/2011 1 Freq: 50 MHz Proc: Dewow + SEC2 Gain (Attenuation: 0.69 Start Gain: 0.90 Maximum Gain: 50)
NE

Appendix G – River and Rainfall Data

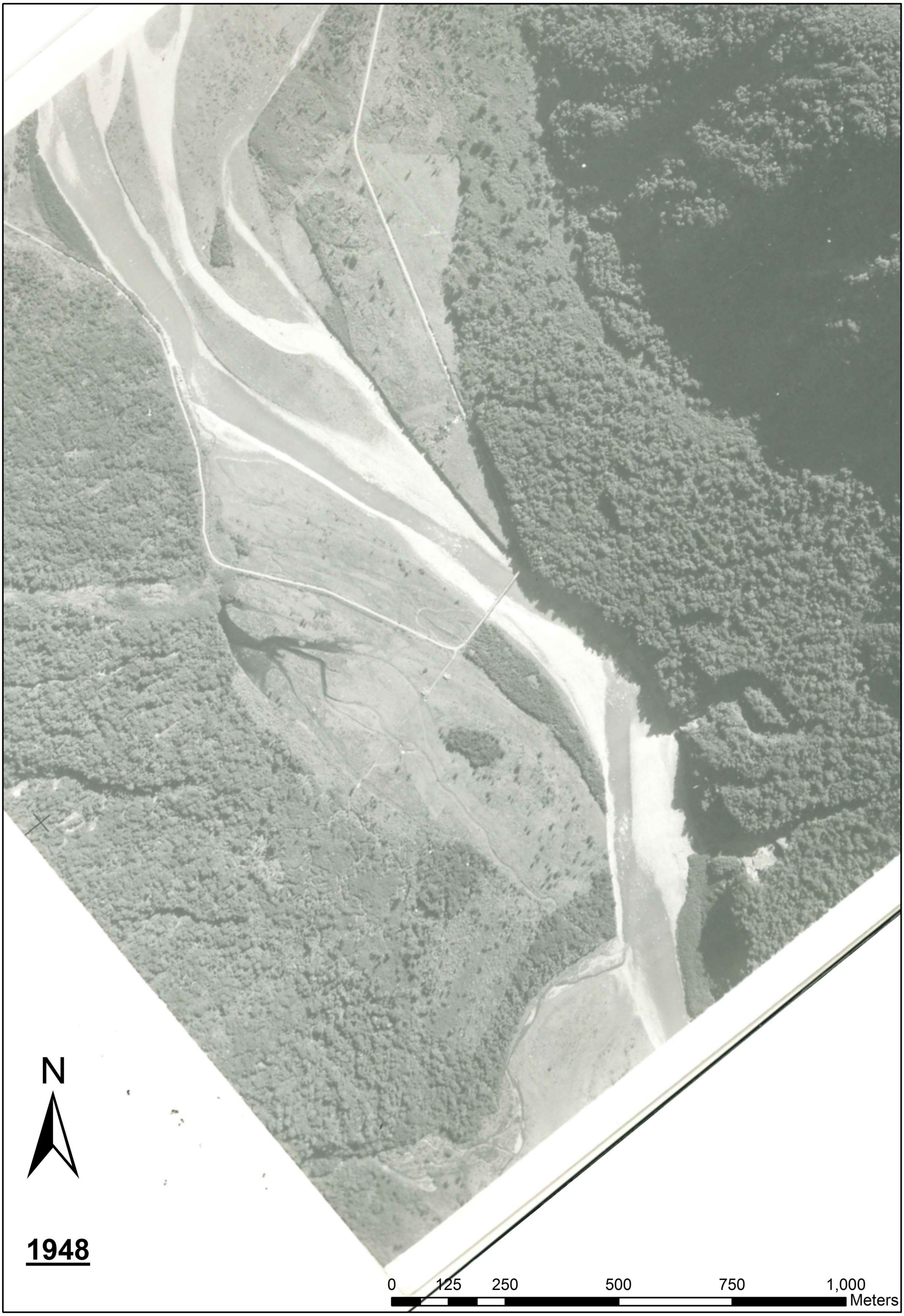

River Flow at Site 89301, Whataroa State Highway Bridge
Flow (l/s)
3000000
2500000
2000000
1500000
1000000
500000
0
18-Dec-85
18-Dec-86
18-Dec-87
18-Dec-88
18-Dec-89
18-Dec-90
18-Dec-91
18-Dec-92
18-Dec-93
18-Dec-94
18-Dec-95
18-Dec-96
18-Dec-97
18-Dec-98
18-Dec-99
18-Dec-00
18-Dec-01
18-Dec-02
18-Dec-03
18-Dec-04
18-Dec-05
18-Dec-06
18-Dec-07
18-Dec-08
18-Dec-09
18-Dec-10
Date
River Flow (l/s)


River Level at Site 89301, Whataroa State Highway Bridge
Stage (mm)
6000
5000
4000
3000
2000
1000
0
18-Dec-85
18-Dec-86
18-Dec-87
18-Dec-88
18-Dec-89
18-Dec-90
18-Dec-91
18-Dec-92
18-Dec-93
18-Dec-94
18-Dec-95
18-Dec-96
18-Dec-97
18-Dec-98
18-Dec-99
18-Dec-00
18-Dec-01
18-Dec-02
18-Dec-03
18-Dec-04
18-Dec-05
18-Dec-06
18-Dec-07
18-Dec-08
18-Dec-09
18-Dec-10
Date
River Level (mm)



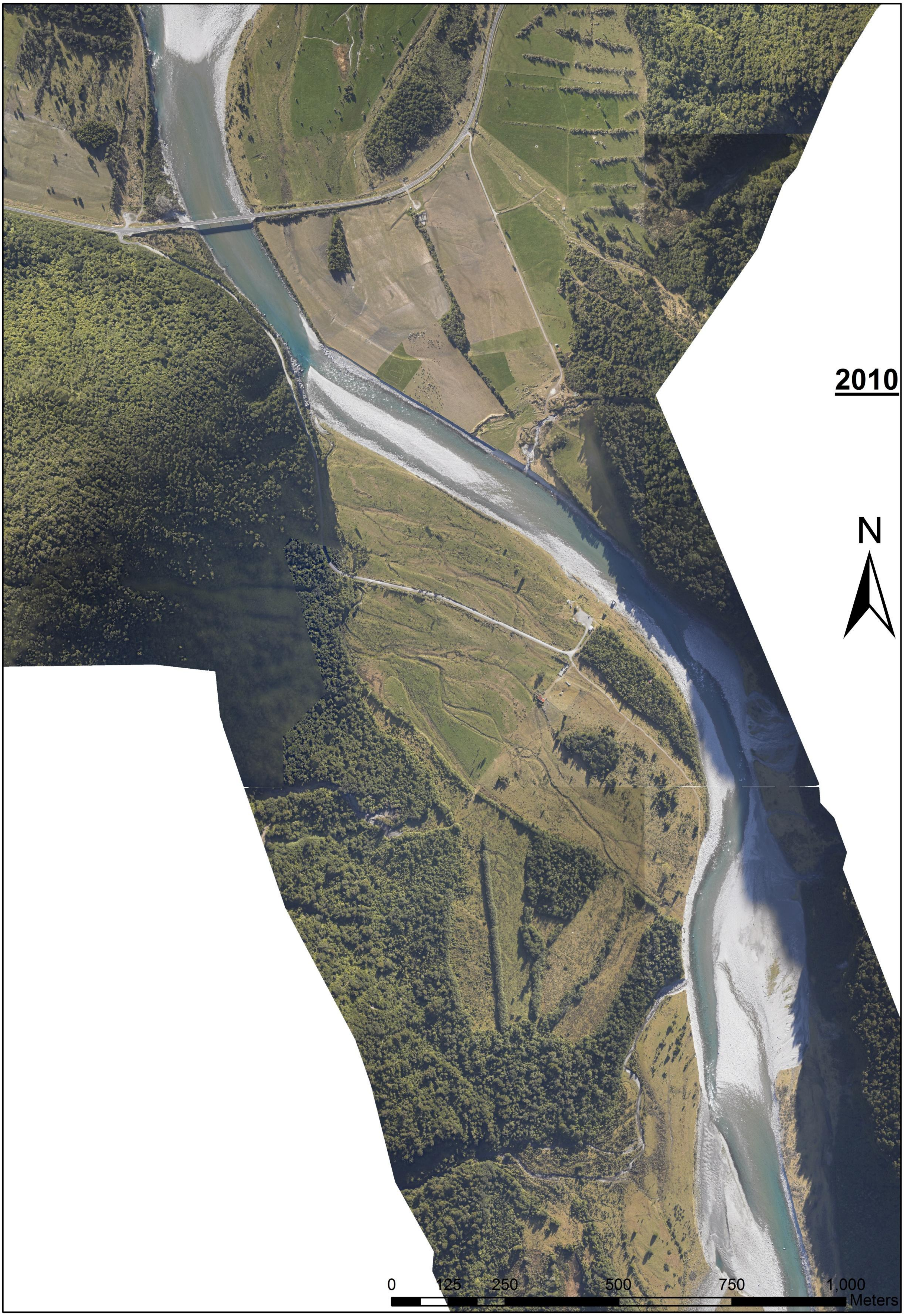
Rainfall at Site 303411, Whataroa State Highway Bridge
Rain (mm)
350
300
250
200
150
100
50
0
17-Jun-89
17-Jun-90
17-Jun-91
17-Jun-92
17-Jun-93
17-Jun-94
17-Jun-95
17-Jun-96
17-Jun-97
17-Jun-98
17-Jun-99
17-Jun-00
17-Jun-01
17-Jun-02
17-Jun-03
17-Jun-04
17-Jun-05
17-Jun-06
17-Jun-07
17-Jun-08
17-Jun-09
17-Jun-10
Date
Rainfall (mm)

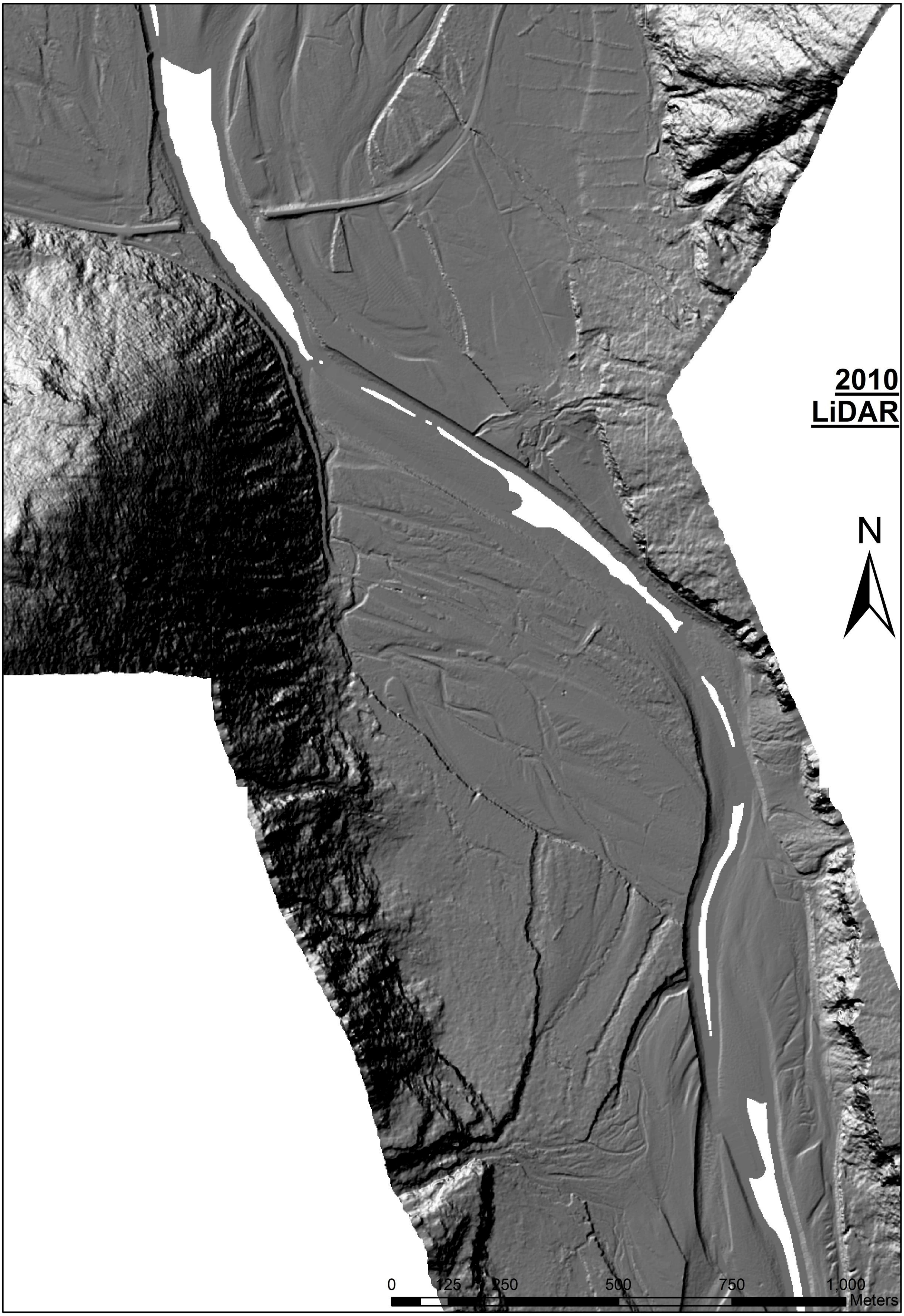
Appendix H – Aerial Photographs


N
1948
0
125
250
500
750
1,000
Meters

N
© 2011 Cnes/Spot Image
© 2011 Whereis® Sensis Pty Ltd
Image © 2011 DigitalGlobe
43°18'18.75" S 170°24'53.56" E elev 99 m
2002
©2010
0 125 250 500 750 1,000
Meters

2002


2010
N
0
125
250
500
750
1,000
Meters



2010
LiDAR
N
0
125
250
500
750
1,000
Meters

Appendix I – Trench Location

	Height (m)	Latitude	Longitude
Start	109.503	-43.29924748	170.4091699
End	110.727	-43.29932704	170.4091152